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The Forest and Agricultural Sector Optimization Model (FASOM): Model Structure and Policy Applications

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Abstract

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The Forest and Agricultural Sector Optimization Model (FASOM) is a dynamic, nonlinear programming model of the forest and agricultural sectors in the United States. The FASOM model initially was developed to evaluate welfare and market impacts of alternative policies for sequestering carbon in trees but also has been applied to a wider range of forest and agricultural sector policy scenarios. We describe the model structure and give selected examples of policy applications. A summary of the data sources, input data file format, and the methods used to develop the input data files also are provided.

Keywords: Economics, forest sector, reforestation, afforestation, policy scenarios, models.

Summary

Recent concern over accumulation of atmospheric carbon dioxide has prompted the development of options for mitigation strategies to prevent climate change, including strategies to increase carbon sequestration in U.S. forests. The FASOM model initially was developed to evaluate welfare and market impacts of alternative policies for sequestering carbon in trees, but since its development it has been applied to a wider range of forest and agricultural policy scenarios. The FASOM modeling system has a joint, price-endogenous, spatial equilibrium market structure, with the linked agricultural and forestry sectors competing for a portion of the land base. Prices for agricultural and forest sector commodities and land are endogenously determined given demand functions and supply processes. The structure of the two sectors is based in part on elements of the TAMM and ASM models. Unlike TAMM, decisions pertaining to land use and timber management investment in FASOM are endogenous.

Intersectoral land transfers are important in the analysis of sector-specific and cross-sectoral policies, but land does not transfer freely in FASOM. The FASOM model was developed with (a) explicit land balances in each sector, (b) land transfer costs, and (c) limits on land transfers based on land suitability. Through an optimization approach, the FASOM model maximizes the net present value of the sum of consumers' and producers' surpluses (for each sector), with producers' surplus interpreted as the net returns from forest and agricultural sector activities. Farmers and private timberland owners are assumed to have perfect foresight regarding the consequences of their behavior; that is, expected future prices and the prices realized are identical. The model provides estimates of economic welfare disaggregated by agricultural producers, timberland owners, consumers of agricultural products, and purchasers of stumpage.

The GAMS programming language is used for the compact representation of the large forestry and agricultural sectors and to solve the model; it was formulated originally as a nonlinear mathematical programming problem. The programming structure allows easy expansion of the FASOM model. FASOM can model the forest and agricultural sectors either independently or simultaneously. The modeling system is designed to provide information about the effects of a wide range of potential policies on carbon sequestration, market prices, land allocation, and consumer and producer welfare under alternative supply and demand scenarios and producer eligibility-participation constraints. The modeling system is designed so that the sensitivities of these policies and their results can be evaluated given different assumptions about policy structure and finances.

Contents

Introduction

This report provides a description of the structure of the Forest and Agricultural Sector Optimization Model (FASOM), a dynamic, nonlinear programming model of the forest and agricultural sectors in the United States. The model depicts the allocation of land over time for competing activities in the two sectors. The model was developed to evaluate the welfare and market impacts of alternative policies for sequestering carbon in trees. It also can aid in appraising a wide range of forest and agricultural sector policies.

The conceptual structure of FASOM is an outgrowth of two previous studies. In the first of these, Adams and others (1993) modified an existing, price-endogenous, agricultural sector model (ASM) developed by McCarl and others (in press) to include consideration of tree planting and harvest on agricultural land to sequester carbon. The study provides estimates of (a) costs of sequestering carbon that take into account the increases in agricultural prices when agricultural crops are displaced by trees, and (b) impacts of different sizes of programs on both the total and the distribution of the consumers' and producers' welfare. The study showed that harvesting the trees used to sequester carbon has the potential to greatly depress regional stumpage prices in the United States. A significant limitation of this study is that there is no way to include the dynamics of tree growth (that is, trees are assumed to be harvested in a uniform, steady-state fashion). A subsequent study (Haynes and others 1994) employed the timber assessment market model (TAMM; Adams and Haynes, in press) and a linked inventory model (ATLAS; Mills and Kincaid 1992), and as expected, the inventory of existing trees acted to spread out the period during which the trees that had been planted to sequester carbon were harvested. Modeling the dynamics of the forest inventory has the effect of damping the decreases in stumpage prices relative to the results in Adams and others (1993).

The structure of the models in the two previous studies precludes examining effects of future price expectations on the behavior of the owners of existing private timberland as well as the likely impacts on the total amount of carbon sequestered. A major driving force in the creation of FASOM was the need to model the intertemporal optimizing behavior of the economic agents that would be affected by carbon sequestration policies. Harvest and reforestation (or afforestation) decisions by private timberland owners are likely to be influenced by farmers planting millions of acres of potentially harvestable timber. If timberland owners thought these trees would be harvested sometime in the future, they probably would take actions to reduce the size of their inventory holdings by harvesting sooner, reforesting at a lower management intensity, or shifting investment to other sectors of the economy. This would reduce the price impacts of "tree dumping" on the forest sector, but it also would reduce the amount of sequestered carbon. The former limitation is addressed by specifically linking the forest and agricultural sectors in a dynamic framework, so that producers in both sectors can, in effect, foresee the future consequences of alternative tree planting policies and take action to accommodate the future effects.

Linking the two sectors in a dynamic framework also allows for land price equilibration in the sectors, in contrast to the static, partial equilibrium (for example, one-sector) framework of earlier studies. FASOM allows transfers of land between sectors, based on the land's marginal profitability in all alternative forest and agricultural uses across the time horizon of the model.

This report describes the structure of the FASOM model primarily in conceptual terms, as opposed to a detailed mathematical depiction of the model. The report is divided into three text sections and four appendices. Following this "Introduction," the next section provides an overview of the major features of the model, such as the regional delineation and the basic structure of the forest, agricultural, and carbon accounting sectors in the model. The third text section describes the outputs of the FASOM model, discusses how the model can be used to evaluate alternative policies for sequestering carbon, and outlines potential future directions for the model. Appendices A and B contain additional detail on the scope of the agricultural and forest models, respectively. Appendix C provides a description of the data file structure for the FASOM modeling system as a whole. Appendix D contains a general listing of the outputs of the model.

Model Overview

This section provides a brief description of the major features and important assumptions of the FASOM model. It is followed by brief discussions of each of the sectors in the model: forest, agriculture, and carbon accounting.

Operationally, FASOM is a dynamic, nonlinear, price-endogenous, mathematical programming model. FASOM is dynamic in that it solves jointly for the multimarket, multiperiod equilibrium in each agricultural and log product market included in the model for each model time period, and for the intertemporal optimum in the asset market for land. FASOM is nonlinear because it contains a nonlinear objective function representing the sum of producers' and consumers' surpluses in the markets included in the model. FASOM is price endogenous because the prices of the products produced in the two sectors are determined in the model solution. Finally, FASOM is a mathematical programming model because it uses numerical optimizing techniques to find the multimarket price and quantity vectors that maximize the value of the objective function, subject to a set of constraints and associated right-hand-side values that characterize (a) the transformation of resources into products over time, (b) initial and terminal conditions, (c) the availability of fixed resources, and (d) policy constraints.[1]

FASOM employs 11 supply regions (fig. 1) and a single national demand region. Alaska and Hawaii are not included in the FASOM model. Land use and exchanges of land between sectors in some of the regions are constrained for empirical or practical reasons. Under the current climatic regime, environmental conditions in the Great Plains States are not conducive to significant amounts of commercial forest or cost-effective carbon sequestration activities. These States are important agriculturally, however, and are included in the model only with agricultural sectors. The same is true for the western portions of Texas and Oklahoma. The Pacific Northwest (PNW) was divided into an eastern region (PNWE) and a western region (PNWW) to reflect

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[1] The FASOM objective function depicts maximizing the net present value of producers' and consumers' surpluses, associated with production and price formation in competitive markets over time for both agricultural and forest products. In that sense, the first-order (Kuhn-Tucker) conditions for the choice variables in the model provide a set of rules for economic agents to follow that lead to the establishment of a competitive equilibrium.

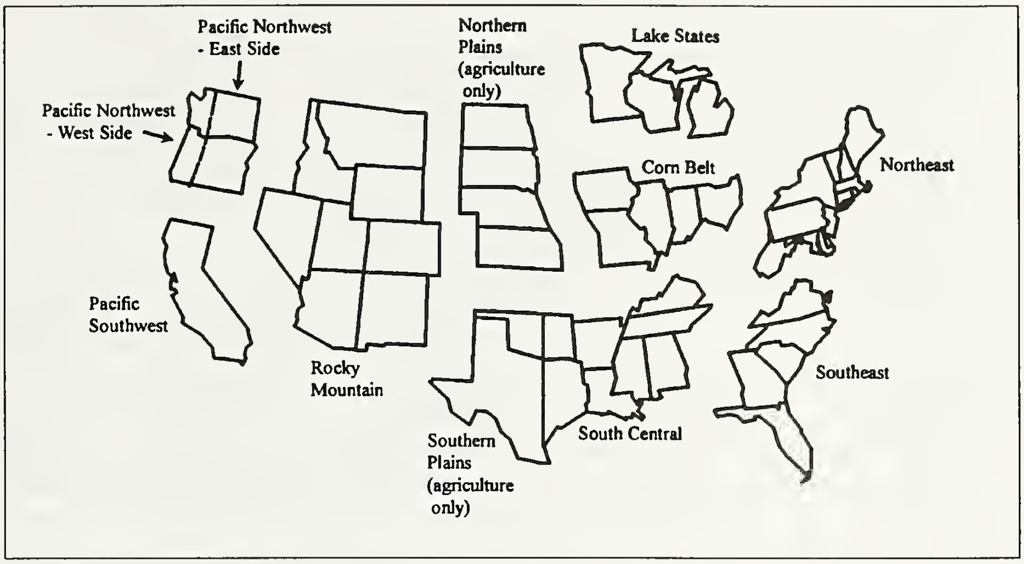

Figure 1—Supply regions used in FASOM.

differences in environmental conditions and production practices on either side of the crest of the Cascade Range in Oregon and Washington. For the PNWW region, it was assumed that land markets are in equilibrium between forest and agricultural uses for the various available classes and sites. A substantial amount of land transfer between agricultural and forestry uses is believed to not be likely. For this reason, and because PNWW agricultural production of the crops modeled in ASM is relatively small, only the forest sector was included for this region.

Production, consumption, and price formation are modeled for hardwood and softwood saw logs, pulpwood, and fuelwood in the forest sector, and 75 primary and secondary crop and livestock commodities in the agricultural sector. The model is designed to simulate market behavior over 100 years with explicit accounting by decade. Policy analysis is limited to results for the 50 years from 1990-2039. The model incorporates national demand curves for forest and agricultural products by decade for the projection period, 1990-2089. The production component includes agricultural crop and livestock operations, as well as private nonindustrial and industrial forestry operations. Harvests from public forest lands are treated as exogenous. From an agriculture policy perspective, the model includes 1990 farm programs for its initial decade, then operates without a farm program from thereon. Supply curves for agricultural products, sequestered carbon, and stumpage are implicitly generated within the system as the outcome of competitive market forces and market adjustments. This is in contrast to supply curves that are estimated from observed, historical data. This approach is useful in part because FASOM will be employed to analyze conditions that fall well outside the range of historical observation (such as large-scale tree planting programs).

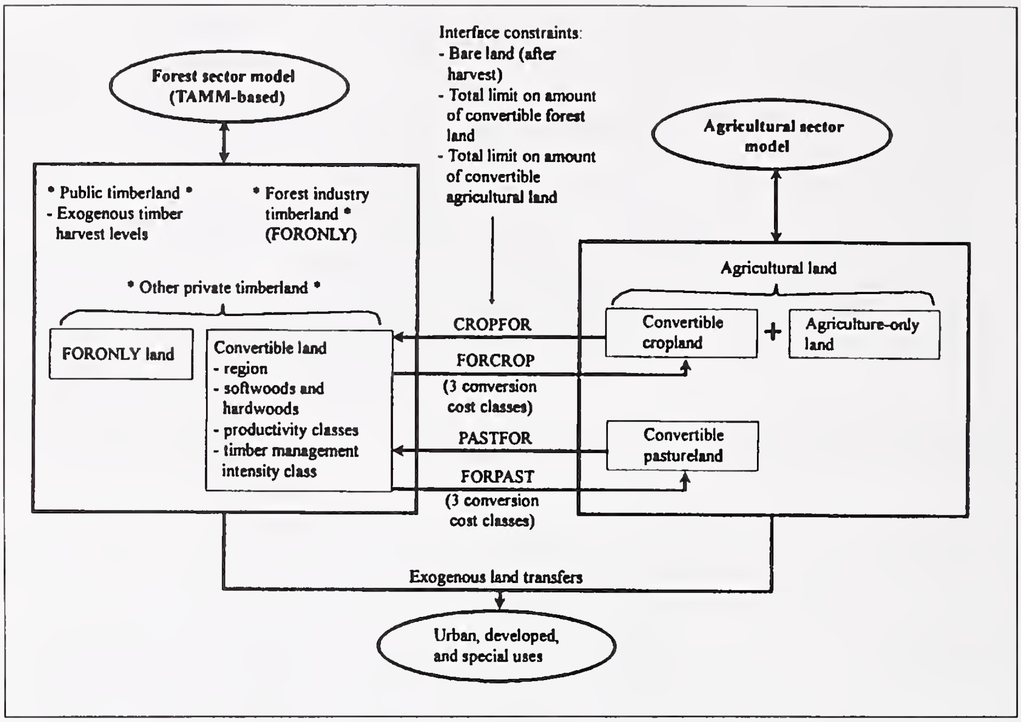

Figure 2—Links of forest and agriculture sectors in FASOM.

The forest sector of FASOM depicts the use of existing private timberland[2] as well as the reforestation decision on harvested land. The flow of land between agriculture and forestry is also an endogenous element of the model (fig. 2). Forested land is differentiated by region, the age cohort of trees,[3] ownership class, cover type, site condition, management regime, and suitability of land for agricultural use. Certain forest lands are unsuitable for agricultural use because of topography, soils, climates, or other characteristics. Other forest lands are suitable for pasture and grazing uses, and yet other lands can be used for crops but require costly site preparation activities. Similarly, the inventory of agricultural lands contains lands not suitable for forestry because of climatic conditions, as well as lands that might support various types of forests with different yield characteristics. FASOM accounts for carbon accumulation in forest ecosystems on private timberland and for the fate of this carbon, both during and after harvest.

[2] Timberland is the subset of forest land that is capable of producing at least 20 cubic feet per acre per year of industrial wood at culmination of mean annual increment and is not withdrawn from timber harvesting or related timbering activities.

[3] Forest lands are grouped in ten 10-year cohorts: 0 to 9 years, 10 to 19, ..., 90 + years. Harvesting is assumed to occur at the midyear of the cohort.

The possibility of planting trees with a rotation length sufficient to carry them beyond the explicit time frame of the model necessitates the specification of terminal conditions. At the time of planting, producers should anticipate a flow of costs and returns that justify stand establishment costs. The planting of a stand with an expected 30-year life in year 80 of a 100-year projection is potentially problematic, however, because the anticipated harvest date is beyond the model time frame. A mechanism is needed to reflect the value of inventory carried beyond the explicit model time frame. This is done with "terminal conditions," which represent the projected net present value of an asset for all periods beyond the end of the model projection. Terminal conditions in FASOM are resolved by using downward sloping demand curves for the terminal inventory.

Four types of terminal inventory are valued in FASOM: (a) initial stands that are not harvested during the projection, (b) reforested stands remaining at the end of the projection, (c) undepreciated forest processing capacity, and (d) agricultural land retained in agriculture. Specific valuation approaches for each element are discussed under "Dynamic Structure," below.

FASOM incorporates expectations of future prices. Farmers and timberland owners are modeled as being able to foresee the consequences of their behavior (when they plant trees or crops) on future stumpage and agricultural product prices and incorporate that information into their behavior. The FASOM model uses deterministic expectations, or "perfect foresight," whereby expected future prices and the prices realized in the future are identical.

FASOM models forest inventory by using the same age-based structure as ATLAS and basic inventory data drawn from the 1993 RPA timber assessment update database (Haynes and others 1995). Relative density adjustment mechanisms and other growth and yield projection guides are based on those in the ATLAS system.

Unlike those in TAMM, decisions in FASOM pertaining to timber management investment are endogenous. Actions on the inventory are depicted in a framework allowing timberland owners and agricultural producers to institute management activities that alter the inventory, consistent with maximizing the net present value of the returns from the activities.

The modeling system performs carbon accounting in both sectors. Carbon accounting in the model includes carbon in growing stock, soil, understory, forest floor, woody debris, forest products, landfills, and displaced fossil fuels.

Forest Sector

The forest sector in FASOM consists of the following basic building blocks: (a) demand functions for forest products; (b) timberland area, inventory structure, and dynamics; and (c) production technology and costs.

Product demand functions—FASOM employs a single national demand region for forest products, which treats only the **log** market portion of the sector. There is currently, in fact, very little interregional shipment of logs in the U.S. forest sector. Competitive price relations among regions at the log and stumpage market levels are maintained through extensive trade and competition at the secondary product level (lumber, plywood, pulp, and so forth). Use of a single consuming region for logs emulates the effects of competition at higher market levels without the use of an explicit representation of activity at these levels.

The demand for logs derives from the manufacture of products at higher market levels. In FASOM, log demands are aggregated into six categories: saw logs, pulpwood, and fuelwood for both softwoods and hardwoods. Log volumes are adjusted to exclude all but the growing stock portion.[4] Thus, demand is for growing stock log volumes delivered to processing facilities. Log demand curves are derived from solutions of the TAMM and North American pulp and paper (NAPAP; Ince 1994) models by summing regional derived demands for logs from manufacturing at higher market levels (saw logs from TAMM, pulpwood from NAPAP). Fuelwood demand, which is not price sensitive in TAMM, is represented by a fixed minimum demand quantity and a fixed price. National fuelwood demand volumes, by decade, were derived from appropriate scenarios in Haynes and others (1995). Demand curves are linearized about the point of total decade quantity and average decade price. Demand curves shift from decade to decade to reflect changes in the underlying secondary product demand environment, secondary processing technology, and secondary product capacity adjustment across regions.[5]

Offshore trade in forest products occurs at the supply region level and includes both softwood and hardwood saw logs and pulpwood. Fuelwood is not traded. Price-sensitive, linear demand (export) or excess supply (import) relations were developed for the various regions and products as appropriate for their current trade position. For example, the PNWW region faces a net export demand function for softwood saw logs but no offshore trade demand for hardwood products or other softwood **log** products.

Inventory structure—Descriptors used in FASOM to characterize the structure of the inventory on private timberland in each region are shown in figure 3. FASOM characterizes private timberland in terms of several strata or states that are differentiated by nine geographic regions, two classes of private ownership (industrial—integrated with processing facilities—and nonindustrial), four forest types (referred to as “species” in subsequent discussions to indicate species composition, either softwoods or hardwoods, in the current and immediately preceding rotation), three site productivities (potential for wood volume growth), four management intensities (timber management regimes applied to the area),[6] suitability for transfer to or from agricultural use (referred to as “land class” in subsequent discussions and comprising classes for crop or pasture plus a “forest only” class that cannot shift use), and ten 10-year age classes. Each stratum is represented by the number of timberland acres and the growing stock timber volume per unit area (in cubic feet per acre) that it

[4] Nongrowing stock volumes are included only for carbon accounting.

[5] For both saw logs and pulpwood, “national” price is taken as the highest of the regional average prices observed during the 1980s (see appendix B).

[6] The four management intensity classes are (1) passive—no management intervention of any kind between harvests of naturally regenerated aggregates; (2) low—custodial management of naturally regenerated aggregates; (3) medium—minimal management in planted aggregates; and (4) high—genetically improved stock, fertilization, or other intermediate stand treatments in planted aggregates (see appendix B for more details).

Region	Land class	Owner	Species	Site class	Management intensity class	Age class (cohort)
Northeast	Forest only	Forest industry	Softwood to softwood	High	High	0 to 9
Lake States	Cropland to forest	Other private	Hardwood to hardwood	Medium	Medium	10 to 19
Corn Belt	Pastureland to forest		Hardwood to softwood	Low	Low	20 to 29
Southeast	Forest to cropland		Softwood to hardwood		Low-low	30 to 39
South Central	Forest to pastureland					40 to 49
Rocky Mountain						50 to 59
Pacific Southwest						60 to 69
Pacific Northwest - West side						70 to 79
						80 to 89
Pacific Northwest - East side						90 +

Figure 3—Strata used in FASOM: region, land class, owner, species, site, management intensity class, and age cohort.

contains. Inventory estimates for the existing forest inventory on private timberland are drawn from data used in Powell and others (1993) and Haynes and others (1995). Inventories on public lands are not explicitly modeled and public timber harvests are taken as exogenous.

Any portion, from 0 to 100 percent, of a stratum can be harvested at a time. Harvested acres flow into a pool, from which they can be allocated to new timber stands by using one of several different modes of regeneration, or be shifted to agricultural use. FASOM allows use of several different levels of management intensity for newly regenerated stands. Even though management intensity shifts cannot occur after a stand has been regenerated, this is not thought to be a problem, given that the model employs perfect foresight in allocating land to competing activities.

FASOM simulates the growth of existing and regenerated stands by means of timber yield tables, which give the net wood volume per acre in unharvested stands for strata by age cohort. Relative density adjustment mechanisms (Mills and Kincaid 1992) were used in deriving yields for existing timberland and for any timberland regenerated into the low timber management class. Timber yields for plantations on agricultural lands were based on the most recent reconciled estimates by Moulton and Richards (1990) and Birdsey (1992a).[7]

[7] Timber yields contained in Moulton and Richards (1990) were derived from estimates for plantations from Risbrudt and Ellefson (1983). In some cases, such as for the Rocky Mountains region, these estimates have been the subject of some debate because they are fairly high relative to yields on timberland. Estimates of timber yields used by Birdsey (1992a), based on yield tables in ATLAS used for RPA assessment, are much lower. The two groups of researchers currently are working on reconciling their differences.

Timberland in various public ownerships—including Federal, state, and local public owners—represents about 30 percent of the timberland and about 20 percent of the forest land in the United States. When the FASOM model was developed, timber inventory data were not available for these lands in several key regions. Thus FASOM does not model their inventory, and harvest of public timber is taken as exogenous.

Nontimberland, forested land constitutes about 30 percent of the forest land in the United States. These lands include transition zones, such as those between forested and nonforested lands, and other areas stocked at least 10 percent with forest trees. It also includes forest areas adjacent to urban and built-up lands (for example, Montgomery County, MD) and some pinyon-juniper and chaparral areas of the West. Although the land area in this category is large, data on site quality and inventory structure are generally unavailable. Thus, harvest on this land is taken as exogenous, and changes in inventory volumes or structure are not accounted for in the model.[8]

Production technology, costs, and capacity adjustment—Harvest of an acre of timberland involves the simultaneous production of some mix of softwood and hardwood timber volume. In FASOM this is translated into hardwood and softwood products (saw logs, pulpwood, and fuelwood) in proportions assumed to be fixed. The product mix differs across sites and other land strata, changes over time as the stand ages, and can change between rotations if the management regime (management intensity) changes. Downward substitution (use of a log destined for a higher valued product in a lower valued application) is allowed when the price spread between pairs of products is eliminated. Saw logs can be substituted for pulpwood and pulpwood, in turn, can be substituted for fuelwood, provided that the prices of saw logs and pulpwood, respectively, fall low enough to become competitive substitutes for pulpwood and fuelwood. This “down grading” or interproduct substitution is technically realistic and prevents the price of pulpwood from rising above that of saw logs and the price of fuelwood from rising above that of pulpwood.

Strata in the inventory have specific management (planting and tending) costs that differ with inventory characteristics and type of management. These costs were derived from a variety of sources, including Moulton and Richards (1990) and those used in the 1989 RPA timber assessment (Alig and others 1992).[9] Each product, in turn, has specific harvesting and hauling costs (hauling in this instance relates to the movement of logs from the woods to a regional concentration or delivery point). These costs were derived from the TAMM data base and cost projections used in the 1993 RPA timber assessment update (Haynes and others 1995).

Consumption of saw logs and pulpwood in any given period is restricted by available processing capacity in the industries using these inputs. Investment in additional capacity is made endogenous by allowing purchase of capacity increments at externally specified prices. This raises the current capacity bound, and the bounds in future periods as well. It also reduces producers' surplus by the cost of the capacity

[8] Because this land is not very productive and is widely dispersed among private owners with a variety of management objectives, it is a very difficult target for either regulatory or incentive-based forest management-carbon sequestration programs.

[9] See appendix B for a more detailed description of the timber growth and yield, management costs, and assumptions about trends in nonagricultural uses of forested lands.

acquisition. Over time, capacity declines by an externally specified depreciation rate. Capacity increments in any period also are limited by preset bounds. Because capacity may be added but not fully depreciated before the end of the projection, the objective function is augmented by a term giving the current market value of the undepreciated stock.

The basic form of the forest sector model is a "model II" even-aged harvest scheduling structure (Johnson and Scheurman 1977) or a "transition" timber supply model (Binkley 1987). A mathematical description is given by Adams and others (1996). Figure 4 shows a simplified tableau (for a two-decade projection) emphasizing the forest sector and illustrating the interperiod link of existing, new or regenerated, and terminal timber stands.

Agricultural Sector

A version of the ASM model (Chang and others 1992) was incorporated into FASOM. The ASM model adapted for use in FASOM is described in detail in appendix A, with an overview given in Chang and others (1992) and more details provided by McCarl and others (in press). The only real difference from the full ASM is in regional delineation. The model here is aggregated to the 11 FASOM regions (without any variables in the PNWW region), whereas the ASM model is organized around 63 state-level and substate-level production regions.

Operationally, ASM is a price-endogenous agricultural sector model. It simulates the production of 36 primary crop and livestock commodities and 39 secondary, or processed, commodities. Crops compete regionally for land, labor, and irrigation water. The cost of these and other inputs are included in the budgets for regional production variables for each decade modeled in FASOM. There are more than 200 production possibilities (budgets) representing agricultural production in each decade. These include field crop, livestock, and tree production. The field crop variables also are divided into irrigated and nonirrigated production according to the irrigation facilities available in each region.

Secondary commodities are produced by processing variables: soybean crushing, corn wet-milling, potato processing, sweetener manufacturing, mixing of various livestock and poultry feeds, and the conversion of livestock and milk into consumable meat and dairy products. The processing cost of each commodity is calculated as the difference between its price and the costs of the primary commodity inputs.

A unique feature of ASM is the method it uses to prevent unrealistic combinations of crops from entering the optimal solution, a common problem in mathematical programming models. Although the agricultural sector in FASOM is divided into 10 homogenous production areas, each having available many production possibilities, it often happens that the optimal, unconstrained solution in some regions is represented by one crop budget—complete specialization. In reality, risks associated with weather and the effects of other exogenous and sometimes transient variables on agricultural prices lead to diversification in crop mixes, and such a representation cannot capture the full factor-product substitution possibilities in each area. This is avoided by requiring the crops in a region to fall within the mix of crops observed in historical cropping records, as reported in the agricultural statistics series (see for example, USDA 1990). The model is constrained so that for each area, the crop mix falls within one of the mixes observed in the past 20 years. These crop mixes are required in the first two decades of FASOM and are relaxed thereafter.

		DECADE 1											DECADE 2								
		FORESTRY						LAND TRANSFER		AGRICULTURE			FORESTRY		LAND TRANSFER		AGRICULTURE				
		HARVEST EXISTING STANDS			REESTABLISH AND HARVEST NEW STANDS																
		CUT DEC 1	CUT DEC 2	CUT NEVER	PLANT DEC 1 CUT DEC 2	PLANT DEC 2 CUT NEVER	FOREST DEMAND	TO AG	FROM AG	PROD	FACTORS	AG DEMAND	REESTABLISH NEW STAND PLANT DEC 2 CUT NEVER	FOREST DEMAND	TO AG	FROM AG	PROD	FACTORS	AG DEMAND	FORESTRY TERMINAL HARVEST	RHS
	WELFARE	-a	-a	-a	-a	-a	+b	-a		-a	-a	+b	-a	+b	-a		-a	-a	+b	+b	
Decade 1	EXISTING STANDS	+1	+1	+1																	≤+b
	NEW STANDS	-1			+1	+1		+1	-1												≤ -a
	FOR PROD BALANCE	-a					+1														≤ +b
	AG LAND							-1	+1	+1											≤ +b
	AG PROD									-a		+1									≤ 0
	AG FACTORS									+b	-1										≤ 0
Decade 2	NEW STAND		-1		-1								+1		+1	-1					≤ -a
	FOR PROD BALANCE		-a		-a									+1							≤ 0
	AG LAND							-1	+1						-1	+1	+1				≤+b
	AG PROD																-a		+1		≤ 0
	AG FACTORS																+b	-1			≤ 0
	LAND TRANSFER LIM TO AG							+1	-1						+1	-1					≤+b
	LAND TRANSFER LIM TO FOR							-1	+1						-1	+1					≤+b
	TERMINAL INVENTORY			-a		-a							-a							+1	≤+b

Note: -a is any negative number; +b is any positive number.

Figure 4—Simplified tableau emphasizing forest sector and intertemporal links.

Primary and secondary commodities are sold to national demands. These demand functions are characterized by either constant elasticity or linear functions. The integrals of these demand functions represent total willingness to pay for agricultural products. The difference between total willingness to pay and production and processing costs is equal to the sum of producers' and consumers' surpluses. Maximizing of the sum of these surpluses constitutes the objective function in ASM. Figure 5 gives a simplified description of the agricultural sector in FASOM.

The original long-term equilibrium form of ASM was converted to a (disequilibrium) time step by decade. The basic relations in ASM were treated as if they represented a typical year in each decade. Demand and supply components are updated between decades by means of projected growth rates in yield, processing efficiency, domestic demand, exports, and imports.

The most important feature about the land-use decision that is simulated in FASOM is that, in each period, owners of agricultural land can decide (a) whether to keep each acre of land in agricultural production or plant trees; (b) what crop-commodity mix to plant and harvest, if the land stays in agricultural land use; and (c) what type of timber management to select, if the land is to be planted in trees. These decisions are made based entirely on the relative profitability of land in its various competing alternative uses over the life-span of the foreseeable choices (for land in either crops or trees).

Correspondingly, owners of timberland can decide in each period (a) whether to harvest a stand or keep it for another decade; (b) whether to replant a harvested stand in trees or convert to agricultural crops; (c) what type of timber management to select if the land is planted in trees; and (d) what crop-commodity mix to plant and harvest, if the land is converted to agricultural use.

Carbon Sector

The carbon sector in FASOM was designed with four specific objectives. First, FASOM is able to account for changes in the quantities of carbon in the major carbon pools in private timberland and cropland. Second, the carbon sector in FASOM is structured such that policy constraints can be imposed on either (or both) the size of the total carbon pool at any given time or the rate of accumulation of carbon from year to year. Third, these constraints can be imposed by region, owner group, land class, and so forth, consistent with proposed policy instruments. Fourth, the carbon sector has been designed so that carbon can be valued in the objective function, instead of constrained to meet specific targets. This makes it possible to model carbon subsidies directly in the model without having to estimate carbon equivalents associated with specific subsidy prices.

FASOM accounts for five basic functions related to terrestrial carbon: (a) accumulation of carbon in forest ecosystems on existing forest stands in the existing private timberland inventory during the simulation period; (b) accumulation of carbon in forest ecosystems on both regenerated and afforested stands during the simulation period; (c) carbon losses in nonmerchantable carbon pools from harvested stands from the time of harvest until the stand is regenerated or converted into agricultural land; (d) carbon "decay" over time, after harvested stumpage is transformed into products; and (e) carbon on agricultural lands.

	Forestry	Land from Forest	Land to Forest	Prog Crop Prod	Non Prog Crop Prod	Livest ock Prod	Crop Mix	LiveM ix	Land Sup	WaterS up	Labor Sup	Input Purch	Process	Dem and	Export Dem	Import Sup	CCC Loan	Def Pay	OtherF P Pay	
Obj	+	-		-	-	-			-	-	-	-	-	+	+	-	+	+	+	
Forest Land	+	+1	-1																	< +
Crop Land		-1	1	1	1				-											< 0
Max Crop									+											< +
Pasture Land		-1	1			+			-											< 0
Max Past									+											< +
Water				+	+					-										< 0
Fixed Water										+										< +
Labor				+	+	+					-									< 0
Family Labor											+									< 0
Ag Inputs				+	+	+						-	+							< 0
Primary Products				-	-	+/-							+	+	+	-	+	-		< 0
Secondary Products						+							-	+	+	-	+			< 0
Farm Program Products				-														+		< 0
Other Farm Products				-															+	= 0
Crop Mix				+	+		-													= 0
Livestock Mix						+		-												= 0

Figure 5—Simplified tableau emphasizing agricultural sector.

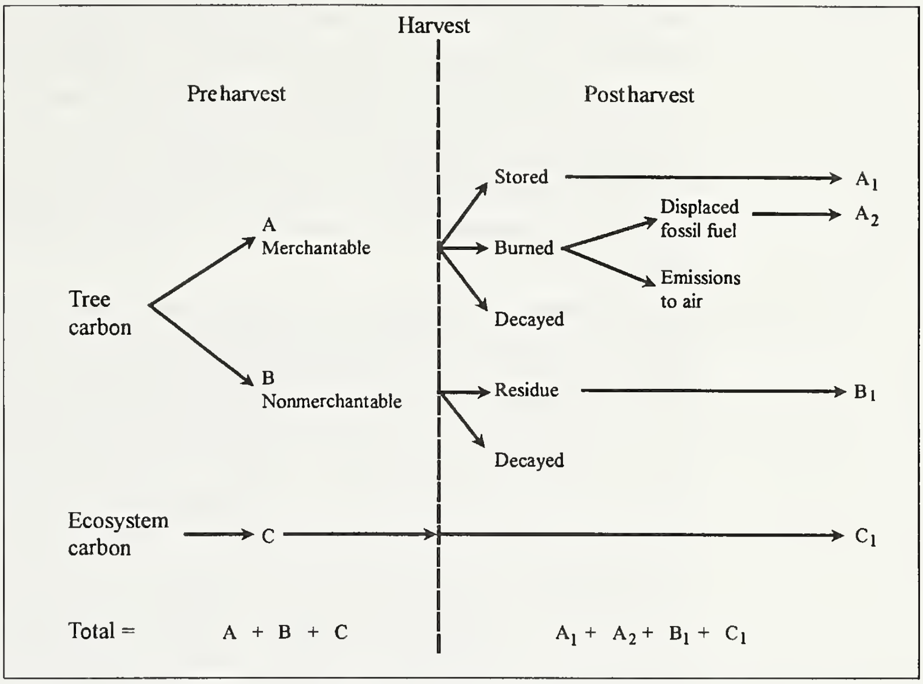

Figure 6—Carbon supply in the understory and forest floor.

The carbon accounting conventions associated with carbon in growing stock biomass and in the soil, forest floor, and understory closely follow the methodology of Birdsey (1992b). Recently, Turner and others (1993) developed a somewhat different approach to carbon accounting, which takes into account the buildup and decay of woody debris on forest stands. The carbon accounting in FASOM includes all these carbon pools.

The carbon accounting structure in FASOM is shown in figure 6. In FASOM, carbon in the forest ecosystem in existing inventory stands is divided into two broad pools. The first of these pools is tree carbon (A), which includes carbon in the merchantable portion of the growing stock volume and in the unmerchantable portion of growing stock volume—the bark, roots, and branches. The second pool consists of ecosystem carbon (C), which includes soil carbon, understory carbon, and forest floor carbon.

When a cohort of trees is harvested in FASOM, the merchantable and unmerchantable portions of tree carbon are physically separated and follow different life cycles. In any period, merchantable carbon follows one of three different paths. Some portion of this carbon pool is stored in wood products or landfills (A_1), is burned (A_2), or oxidizes to the atmosphere in the form of decay. In FASOM not all burnt carbon is lost immediately, however. Some portion of it displaces existing fossil fuel emissions, while the remainder represents emissions to the atmosphere. In FASOM, the fractions that determine the distribution of merchantable carbon and burned carbon change from period to period.

Nonmerchantable carbon has a somewhat simpler life cycle in FASOM. The fraction of the growing stock not harvested represents woody debris or residue (fig. 6). Some portion of this residue survives, while the remainder is oxidized in the form of decay. As in the case of the merchantable carbon pool, the fractions that determine the distribution of nonmerchantable carbon change from year to year.

The continuity of ecosystem carbon over time is somewhat more complicated to characterize; we will address that in the discussion of soil carbon, below.

Preharvest carbon accumulation—In FASOM, carbon is accumulated on existing forested land, on agricultural lands converted into forested land, and on any land planted in trees in subsequent rotations past the first. As stated earlier, the total carbon stored in the forest ecosystem of an unharvested stand is composed of the following four carbon pools: tree carbon, soil carbon, forest floor carbon, and understory carbon.

Tree carbon—On average, tree carbon ranges from as low as 30 percent of ecosystem carbon to about half of total ecosystem carbon, depending on species, region, and age. Tree carbon for a stand in FASOM, before harvest, is the product of three factors: (a) merchantable volume, (b) the ratio of total volume to merchantable volume in the stand, and (c) a carbon factor that translates tree volume into carbon. Merchantable volume, by age, on each representative stand is obtained from the growth and yield tables in the model. The volume factor and carbon factor parameters differ with species and region and are obtained from Birdsey (1992b).

Soil carbon—Of the four pools, soil carbon is, on average, the second-largest contributor to total ecosystem carbon.[10] Our treatment of this pool generally follows that of Birdsey (1992b). This approach, which is also applied to forest floor and understory carbon, is shown in figure 7. For both afforested and reforested stands, the approach assumes that soil carbon is fixed at a positive, initial level (which changes with land type and region) with regeneration of a new stand. In afforested stands, soil carbon then increases by a fixed annual increment until it reaches another fixed value (which differs with region and species) at a critical age (somewhere between 50 and 60 years). In reforested stands, soil carbon decreases initially and then increases until it once again reaches the initial level at the critical stand age. After that, soil carbon increases at a decreasing rate over time, until the tree is harvested. (The postharvest pattern of soil carbon, and understory and forest floor carbon, as shown in figure 7, will be discussed below.)

In Birdsey's formulation, soil carbon is independent of tree carbon and merchantable volume. Consequently, soil carbon can be calculated outside the nonlinear programming (NLP) part of FASOM. In FASOM, soil carbon differs with region, land type, species, and age of a cohort. Estimates of soil carbon, by region, forest type, land type, and age were obtained from Birdsey (1992b).[11] These tables were aggregated into hardwoods and softwoods by using forest-type and species distribution information for 1987 (Waddell and others 1989).

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[10] For some species in some regions, soil carbon yield is actually larger than tree carbon yield at reasonable rotation ages.

[11] Personal communications. September 1992 through June 1993. Rich Birdsey, Program Manager, Northeast Forest Experiment Station, 5 Radnor Corporate Center, Suite 200, Radnor, PA 19087-4585.

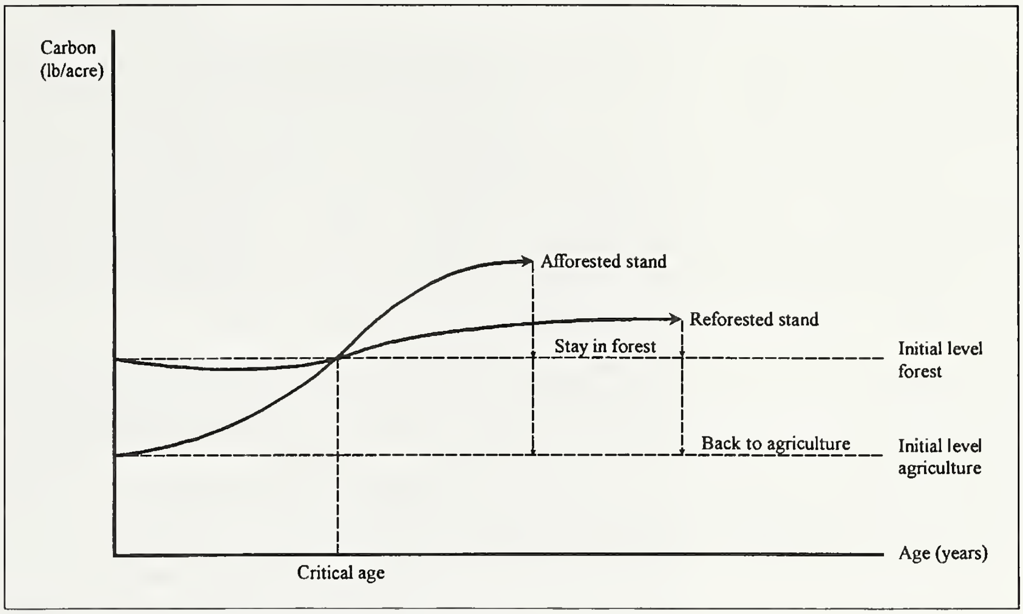

Figure 7—Carbon accounting structure in FASOM.

Forest floor carbon—Forest floor carbon is the third largest carbon storage pool, but it is much smaller than the previous two. Birdsey (1992b) treats forest floor carbon in a fashion similar to soil carbon; that is, forest floor carbon values are fixed at regeneration and then increase by a constant annual increment up to another fixed value at a given critical age. Once the critical age is achieved, forest floor carbon increases at a declining rate over time, until the tree is harvested. Similar to soil carbon, forest floor carbon is independent of tree carbon and merchantable volume. Consequently, it can be calculated outside the NLP part of FASOM. Like soil carbon, forest floor carbon differs with region, land type, species, and age of a cohort. Estimates of forest floor carbon, by region, forest type, land type, and age were obtained from USDA. These tables were aggregated into hardwoods and softwoods by using forest type and species distribution information for 1987 from Waddell and others (1989).

Understory carbon yield—Understory carbon yield is quite small, usually less than 1 percent of total ecosystem carbon. In Birdsey's formulation, understory yield is fixed at age 5, depending on region and species. Understory yield increases from age 5 to a critical age (50 or 55) by a constant annual increment. Understory yield at the critical age, and in all subsequent years, is computed as a fixed fraction of tree carbon yield that ranges between about 0.007 and 0.02, depending on region and species. Unlike soil carbon and forest floor yields, understory yield does depend on tree carbon yield.

Because understory carbon is such a small fraction of the total carbon in a forest ecosystem, and because it is dependent on tree carbon yield for only a portion of the life cycle of a tree, we decided to model understory carbon yield as effectively independent of tree carbon yield in the model. As such, this pool could be treated just like soil and forest floor carbon. Similar to the above three carbon pools, understory carbon differs with region, land type, species, and age of a cohort in FASOM. Estimates of understory carbon, by region, forest type, land type, and age were obtained from Birdsey (1992b). These tables were aggregated into hardwoods and softwoods by using forest type and species distribution information for 1987 from Waddell and others (1989).

Carbon at harvest—FASOM simulates the fate of carbon stored in the forest ecosystem when a stand is harvested. The fate of carbon at harvest is followed in each of the four pools: tree carbon, soil carbon, forest floor, and understory carbon.

Tree carbon—As stated previously, tree carbon is divided into two smaller pools: (a) merchantable carbon that is translated into products; and (b) nonmerchantable carbon, consisting of carbon in bark, branches, leaves, belowground in roots, and so forth, which are not harvested. Each of these pools is a fixed fraction of tree carbon at the harvest age, as determined by the region- and species-specific volume factors.

When harvest occurs in FASOM, the fraction of total tree carbon that is merchantable is maintained. No losses to this fraction occur at time of harvest. The remaining fraction—carbon that is in nonmerchantable timber—is adjusted to reflect immediate harvest losses. The fraction of tree carbon left on site immediately after a timber harvest was determined by adjusting the nonmerchantable fraction derived from Birdsey's volume factors to agree with information about the magnitude of this fraction from Harmon (1993).

Soil, forest floor, and understory carbon—The treatment of soil, forest floor, and understory carbon at harvest is illustrated in figure 7. When a stand is harvested, it is assumed that carbon in each of the pools will return to an appropriate initial value by the end of the decade in which harvesting occurred. The appropriate initial level depends on the use to which the stand will revert in the subsequent rotation. If a stand in a forest use remains in a forest use, the appropriate initial level for carbon in these pools is that of a forested stand. If a stand in a forest use rotates back into agriculture, then the appropriate initial level for carbon in these pools is that for agricultural land.

Carbon fate in wood products and woody debris—FASOM physically tracks the fate of carbon, after harvest, from both merchantable and nonmerchantable timber carbon pools.

Merchantable carbon—FASOM translates harvested stumpage into three products: saw logs, which are used for lumber, plywood, and other applications requiring large-diameter logs; pulpwood, which is used for paper products; and fuelwood, which is burned. The life cycle of each of these harvested products can differ greatly, depending on both short-term fluctuations in relative prices and long-term technological change. The later life-cycle phases are not modeled as an economic decision in FASOM, however. Instead, data developed by using the HARVCARB model (Row 1992) are used to simulate the fate of carbon in trees after they are harvested, converted into wood and paper products, used in a variety of ways, and then burned or disposed of in landfills.

Specifically, HARVCARB outputs are used to model the fate over time of carbon in saw-log and pulpwood products. The fate of carbon for each product is determined by a set of coefficients showing the average fraction of merchantable carbon remaining after harvesting a specific cohort in each subsequent time period for four different uses: (a) wood products in use, (b) wood products in landfills,[12] (c) burned wood products, and (d) emissions to the atmosphere (that is, oxidization). These carbon fate coefficients differ with product, species, and length of time after harvest. The fate of carbon in wood that is burned is determined by fixed proportions that divide this carbon into two categories: displaced fossil fuels, an addition to the carbon pool, and emissions to the air. These fractions apply for only a single decade. All wood is assumed to be burned within a decade of harvesting.

The same general treatment is accorded fuelwood, except that it is assumed that fuelwood displaces conventional fossil fuels in fixed proportions, thereby representing the average fossil fuel use mix for residential space heating. Thus, not all the carbon released through fuelwood burning will be lost.[13] As for other products that are burned, however, the accounting carries forward for only a single period, to reflect the fact that fuelwood must be used relatively quickly after harvest to be an effective source of space heating fuel.

Nonmerchantable carbon—Nonmerchantable carbon, or woody debris, also decays after harvest. The decay rates differ with region, species, and decade. Data for modeling these decay rates were obtained from Harmon (1993). One problem in tracking the buildup and decay of woody debris is that FASOM does not track stands by acreage after harvest. Once a cohort is harvested in FASOM, the land on which that cohort resided is thrown into an undifferentiated pool of acres from which new acres can be drawn for regeneration purposes. Thus, if one assumes that all nonmerchantable carbon decays at the rates indicated in Harmon's data, there is a tendency for very large accumulations of carbon to develop in this pool. One way to deal with this problem is to truncate the number of periods over which the woody debris from any given cohort can accumulate. A truncation of three to four periods tends to produce a terminal woody debris pool that converges on the size of the pool simulated by Turner and others (1993).[14]

Public and noncommercial timber carbon—The carbon from these sources is not included in FASOM owing to insufficient inventory data of a form consistent with the private timberland data.

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[12] For convenience, the first two categories were combined to reflect a single stored carbon pool, regardless of the life-cycle stage.

[13] The treatment of pulpwood as a fuel for cogeneration is treated explicitly in HARVCARB in the same fashion.

[14] With a truncation of this length, carbon in woody debris accounts for about 8 to 12 percent of the total carbon by 2080, close to the 10-percent estimate obtained by Turner and others (1993) in their simulations.

Dynamic Structure

FASOM contains several important dynamic features involving the structure of and links between various parts of the land base within the model, the terminal conditions, and the objective function. The overall structure of the model is illustrated in figure 8. The forest sector portrays the planting and harvesting of timber (logs) on private lands in U.S. regions and foreign trade in logs. The agricultural sector depicts crop and livestock production and secondary processing by using key water, labor, and forage inputs as well as primary product trade. The sectors are linked through the land transfer activities and constraints.

The forest and agriculture models differ in their temporal representations of the two sectors. Quantities in the forest model represent the aggregate activity of the sector for an entire decade. Transactions were assumed to occur at the midyear in each decade and were discounted in the objective function for that year. The agricultural model, in contrast, represents typical activity during each year of a decade. Thus, agricultural returns in each decade were treated as a terminating annual series of 10 equal amounts under the assumption that the returns arose in each year of each decade. They were then adjusted to the middle year of the decade to correspond to the forest sector.

Dynamic entities—There are four types of dynamic entities related to the land base within the model: (a) existing forest lands, (b) potentially reforestable lands, (c) agricultural lands, and (d) lands transferred between sectors. The model treats each differently.

Timber on existing forested lands is harvested at endogenously determined harvest dates. Maintenance (tending) costs on timberlands are incurred for all years up to the timber harvest date. Once aggregates reach harvest age, land can be released for another use. The land may be either reforested or transferred to agriculture. This decision also embodies a number of dynamic dimensions. The potentially reforestable acres are balanced decade by decade with the land available from forest harvest and inmigration from agriculture. When land is reforested, the model also selects another optimal future harvest date. These acres are then retained in the forest base until their harvest date, at which time another reforestation-transfer decision is made.

Land transferred to and from agriculture can shift uses more than once over the projection period, constrained in part by minimum harvest ages for timber. For example, timberland converted to agriculture for several decades could then shift back to timberland in a subsequent decade.

Terminal inventories—Although the model structure readily treats existing and regenerated forest stands and the uses of agricultural lands during the projection period, additional provisions are required to accommodate net returns from the forest and agricultural sectors beyond the end of the projection period. This is a common issue in dynamic analyses regarding terminal conditions. Because land values in any use reflect the present value of an infinite stream of future net returns, it would be theoretically inappropriate to ignore land values at the end of our finite projection period. In practical terms, some rotation ages in the forest sector can be as long as 90 years, and omission of terminal conditions or terminal land values could lead the model to fail to replant after initial harvest, perhaps as soon as the third decade in the solution. Terminal values are likewise needed in agriculture to prevent the model from simply transforming agriculture lands into forestry to capture net returns beyond the explicit model time horizon.

		FORESTRY VARIABLES							LAND TRANSFER VARIABLE		AGRICULTURAL VARIABLES									
		PRODUCTION		FOREST MARKET				TERMINAL				ANIMAL		FACTOR SUPPLY			AG MARKET			
		HARVEST EXISTING STANDS	HARVEST NEW STANDS	LOG DEMAND	PRODUCT SUBST.	LOG EXPORT	LOG IMPORT	VALUED HARVESTED	TO AG	FROM AG	CROP PROD	PROD	PROCESS	WATER	GRAZING	LABOR	AG DEMAND	AG IMPORT	AG EXPORT	RHS
	OBJECTIVE	-a	-a	+b	-a	+b	-a	+b	-a		-a	-a	-a	-a	-a	-a	+b	-a	+b	Max
Forest EQN	EXISTING STANDS	+1																		≤+b
	NEW STANDS	-1	+/-						+1	-1										≤-a
	LOG DEMAND/ SUPPLY	-a	-a	+1	+b/-a	+1	-1													≤+b
	TERMINAL INVENTORY	-a						+1												≤+b
	LAND TRANSFER LIMIT							+1	+1											≤+b
AG EQN	AG LAND BALANCE								-1	+1	+1	+b								≤+b
	PRIMARY AG PRODUCTION										-a	+b/-a	+b				+b	-a	+b	≤0
	SECONDARY AG PRODUCTION											+b	-a				+b	-a	+b	≤0
	WATER										+b			-a						≤0
	GRAZING											+b			-a					≤0
	LABOR										+b	+b				-a				≤0

Note: -a is any negative number; +b is any positive number.

Figure 8—Schematic tableau of FASOM model showin primary activities and constraints, and relation of forest and agriculture sectors.

Terminal inventories are valued in both sectors assuming perpetual, steady state management following the last year of the time horizon (Adams and others 1996). Demand relations for forestry and agriculture products in all periods beyond the end of the projection were taken to be the same as those in the final (for example, ninth) decade. Thus terminal condition prices and revenues could differ with levels of output. After deducting costs, the resulting streams of net returns were treated as constant perpetual series. In the forestry sector, we used von Mantel's formula (Davis and Johnson 1987) to estimate the perpetual yield of a fully regulated forest with volume equal to the model's terminal inventory at the end of the ninth decade (Adams and others 1996). In the agricultural sector, activity in the last decade was treated as if it continued indefinitely (see appendices A and B for more details).

FASOM Outputs and Policy Applications

This section describes the outputs of the FASOM model and discusses some of the policy questions the model can be used to address. It also describes examples of several possible directions for future model modifications and extensions to improve FASOM and expand the scope of possible policy questions. A listing of model outputs is contained in appendix D.

Model Solution Information

The FASOM solution is addressed here in terms of both the information it yields and the economic properties of that information. The FASOM objective function involves the maximization of the present value of consumers' plus producers' surpluses net of transport and capacity costs. It depicts (assumes), therefore, a multiperiod simulation of economic activity in competitive sectors under perfect foresight of future price conditions. The sizes of timberland holdings are assumed to be small enough that owners do not individually affect prices but are knowledgeable of future forest product prices and land opportunity costs. Harvest decisions are made so that stands are harvested at the point where the (marginal present) value of wood and carbon growth (if priced) is no larger than the (present value of) marginal costs of maintaining the stand plus the marginal opportunity cost of holding the land in the current stand for an additional period (the present value of future rotations). In addition, land will shift into forestry from agriculture if the expected returns in forestry exceed the returns in agriculture over the remaining explicit decades in the model plus the terminal values. The decision regarding transferal of land to agriculture would involve the opposite considerations.

The solution to the nonlinear programming problem in FASOM provides information in eight areas: (a) consumers' and producers' welfare, (b) agricultural production and prices, (c) forest area and inventory volumes, (d) harvest levels and prices, (e) wood product output and prices, (f) land and forest asset values, (g) carbon sequestration amounts and "prices," and (h) land transfers. Appendix D gives a definition of output items from a 1995 version of FASOM.

Consumers' and producers' welfare—As previously stated, the FASOM objective function represents the net present value of consumers' and producers' surpluses in the two sectors. Consumers' surplus is calculated in both sectors. Producers' surplus is calculated regionally. Thus, the model produces information about the distribution of the present and future values of consumers' and producers' surpluses over both space and time.

Agricultural production and prices—FASOM provides regional-level information about the market-clearing production and price levels for ASM commodities by decade. Regional production levels for crops can be further broken down into average yield levels and acreage harvested. Price levels for agricultural products are endogenous in FASOM.

Tree planting programs have the potential to reduce agricultural input use by farmers. Annual management costs associated with tree plantations are considerably below agricultural production costs. Sufficiently large reductions in input use by farmers may cause the prices of some inputs, such as hired labor and water, to decrease. FASOM contains input supply curves for land and hired labor. Consequently, price (and cost) impacts on these inputs are an output of FASOM. The impacts of reductions in the use of other inputs can be measured, in aggregate, by cost decreases to farmers, or as revenue decreases to input suppliers (on the other side of the balance sheet).

Forest inventory levels—For each 10-year period in the simulation, FASOM reports regional inventory levels by owner, land use suitability, species group, site class, management regime, and age—in other words, by each of the dimensions that characterizes a representative inventory aggregate in the model.

Harvest levels and prices—Harvest levels are provided by FASOM at the same level of detail as other inventory statistics. Prices may be examined at either the national or regional levels.

Wood product output and prices—Levels of wood product output levels, by period, are provided for each of the three products (saw logs, pulp, and fuelwood), at least by region and species group. Price levels for these products are endogenous.

Land and forest asset values—Because FASOM simulates the competition between forest and agricultural activities for land, FASOM produces information about marginal land and forest asset values over time. Marginal land values for agricultural and forest land can be determined from shadow prices for the equations representing the potential reforested land balance and agricultural land balance. Asset values for regional inventories can be calculated from this data by using information about volumes per acre from the solution to the NLP.

Carbon sequestration amounts and prices—FASOM produces regional- and national-level information about the total amount of carbon in storage in each period and the storage rate (that is, change in storage) during each period. If carbon is "forced" into the model, then FASOM will generate an estimate of the shadow price associated with that requirement, provided that the constraint is binding.

Land transfers—An important feature of FASOM is the intersectoral link between agriculture and forestry. FASOM was designed so that transfers of land between sectors would occur endogenously within the model as a result of intertemporal economic forces. Thus, an important output of FASOM is the listing of land transfers in each decade. These transfers are shown by region, land class, and sector (from-to) for each decade.

Policy Applications

The initial motivation behind FASOM was to develop a model that could evaluate alternative policies to sequester carbon in an economic framework, one that could take into account not only the impacts of these policies on forest and agricultural sector markets but also the reaction to these policies by consumers and producers in these markets. Subsequently, it became clear that FASOM also could be used to evaluate the carbon consequences of a wide range of forest and agricultural policies, not just those intended to promote carbon sequestration.

The scope of the policies and future scenarios that can be analyzed by FASOM is broad, because FASOM contains representations of both the agricultural and forest sectors. The potential of FASOM as a policy analysis tool can be illustrated by looking briefly at the way the model has been used in selected cases to date.

Forest carbon sequestration programs—A number of different programmatic features can be simulated by using FASOM. One approach involves using FASOM to estimate social welfare costs of different carbon sequestration policies, in terms of both specified carbon levels and timing of carbon sequestration. Alig and others (in press) specified carbon target levels for the United States by decade, although targets could be specified (depending on policy dictates) over a longer time, such as a full 100-year simulation period. No restrictions are placed on how the decadal carbon flux or inventory targets (for example, carbon flux of at least 1.6 gigatonnes per decade beginning in the 2000-2009 decade and all subsequent periods) could be met, and the resulting solutions can be considered least-social-cost allocations of land and investments to meet the targets. Results show that land-use shifts to meet policy targets need not be permanent; implementation of land-use and management changes in a smooth or regular fashion over time may not be optimal; and land-use changes account for the largest part of adjustments to meet policy targets. Results also demonstrated that land-use changes promoted by forest carbon policies (for example, afforestation) may generate compensating land-use transfers. In response to a hypothetical policy requiring afforestation of about 12 million acres of pastureland between 1990 and 1999, other forest land was converted to agriculture, thereby resulting in a net gain in forested acres significantly smaller than suggested in previous studies using static models (Moulton and Richards 1990, Parks and Hardie 1995).

Several efforts have evaluated either the timber supply or the carbon sequestration potential of various types of proposed reforestation programs, such as the Stewardship Incentive Program and America the Beautiful. Earlier studies evaluated the timber supply potential of investment opportunities in the United States as a whole (Dutrow and others 1981, Haynes 1990), while other studies (Alig and others 1992, USDA Forest Service 1988) evaluated forest investment opportunities in the South. A more recent study was undertaken by Moulton and Richards (1990) to look at the carbon sequestration consequences of both afforestation and reforestation programs. These studies identified a range of potentially profitable investments in forest management but did not model the effect of programmatic subsidy levels on investment enrollment. The study by Moulton and Richards, although providing cost-based supply curves for both timber and carbon on reforested land, did not take into account the effect of programmatic subsidy levels on acreage enrollment.

In FASOM, all investments in land compete with each other at the margin in the asset market for land. Forest carbon policies or programs simulated in FASOM have reflected the effects of programmatic subsidy levels on areas enrolled and countervailing land transfers to agriculture (Alig and others, in press).

Changes in farm program payments—FASOM can be set up to include (or exclude) the provisions of the current farm bill or many other farm program alternatives. For example, it is possible to use FASOM to examine the effects of reducing loan rates and target prices while increasing tree planting payments, as in the current Conservation Reserve Program. A scenario simulated by Alig and others (in preparation b) is the elimination of farm programs in the first decade (1990s) of the projection. In this case, FASOM projects a reduction in the forest area converted to agricultural use. The impacts are concentrated in the Eastern United States, where most past land exchanges between forestry and agriculture have occurred.

Changing harvest levels on public timberland—Public policy for National Forest and other public timberland seems to be moving in some cases in the direction of increased set-aside of timberland for nontimber purposes, with either restricted timber harvests or no harvesting of some timberlands. This policy trend, if it continues, will result in smaller amounts of timber harvest from public lands. This will allow carbon stored in existing trees to accumulate further, although at a slower rate as trees in the public inventory grow older. At the same time, potential land on which to plant new trees that can more rapidly sequester carbon will decline. The net impact of these two forces on total carbon sequestration is made uncertain by several factors, including the rate at which carbon in wood products oxidizes after a tree is harvested. Thus, a continuation of current trends on public lands raises important policy questions that cannot be answered easily without a model like FASOM.

Although FASOM currently does not contain a detailed representation of the forest inventory on public lands, it includes harvesting from this land. Reductions in harvests from public lands were simulated by Adams and others (1996), who examined the impact of these reductions on harvesting and on management investment decisions in the private sector. The FASOM simulation results suggest a far more elastic market response to changes in public timber harvest levels than in past studies. Shifts in intertemporal patterns of private investment act to dampen the price and aggregate harvest impacts of public harvest changes over time. Underlying the moderated timber market impacts are larger interregional shifts in harvest and private owner welfare than suggested in earlier studies.

Other applications—The FASOM model also has been used to examine scenarios involving (a) production of biomass-based energy that can displace conventional fossil fuel emissions; (b) capital limitations affecting decisions by nonindustrial private forest owners that pertain to timberland management investment (Alig and others, in preparation a), where in the simulation a limit is placed on the owners' investment budget to constrain it to recent historical levels; and (c) increases in paper recycling as an input in the production of paper and board products in the United States (Adams and others 1994). Other scenarios and illustrative results are discussed by Callaway and others (1995).

Future Directions

One of the principles guiding the development of FASOM involves building the modeling system in stages. The first-generation version incorporates these important features: joint markets and conversion activities, future price expectations, basic timber inventory, timber management investment, and carbon sequestration accounting. Several examples of possible future extensions are discussed next.

Restrictions and rigidities in timberland management investment decisions— In the current model form, timberland management investment decisions depend exclusively on the prospective present net welfare impacts of the activities, where the intertemporal nature of these impacts is known with certainty. Investment decisions adjust "instantaneously" to any changes in externally imposed modeling conditions, such as interest rate, intertemporal demand shifts, and costs, or to conditions created by hypothetical policies, such as the afforestation of marginal agricultural lands to sequester atmospheric carbon. It is commonly suggested, however, that such rapid adjustment does not accurately characterize actual investment behavior in the sense that investment decisions are slow to change and exhibit some inertia.

Restrictions on investment decisions can arise for several reasons (see also Alig and others 1990b): (a) failures in the assumption of perfect capital markets, including capital budgets or restrictions on borrowing (so that not all investments that promise to yield a positive present net welfare impact can be undertaken) and divergence in the lending and borrowing rates realized by investors; (b) lumpiness in investments that impose some minimum size or extent of investment; (c) imperfections in investors' knowledge of future markets, including price impacts of future supplies restricted or augmented by investment decisions (the "price feedback" of investments), ignorance of future demand shifts, and so forth; and (d) forest landowners deriving utility from both the goods that can be consumed by using income derived from timber harvest and directly from the standing stock of timber itself, or the wildlife and other nontimber forest outputs and services that depend on the stock and its characteristics (aesthetic and amenity values).

FASOM could simulate the effects of the first three of these restrictions by (a) introducing bounds or limits on the areas replanted in future time periods as demonstrated by Alig and others (in preparation a), using either a forestry stand-alone version of FASOM or the areas replanted to the higher management intensity classes; (b) imposing explicit investment budgets; (c) raising minimum harvest ages above the implicit optimal levels found in unconstrained runs (forcing retention of stands beyond economically optimal periods); or (d) using any of an array of restrictions decoupling the planting investment decision from perfect information on future prices (for example, by requiring the replanting of some preset portion of the area harvested in each period to the lowest management intensity class or a portion based on some function of past prices).

The fourth restriction involves consideration of the utility function(s) of timber owners. Binkley (1987) and Kuuluvainen and Salo (1991) summarize recent research on the theoretical development and econometric testing of so-called household production models of forest landowner behavior, in which owner utility depends on both harvest income and direct amenity outputs derived from the forest. Because little is known about the form of owner utility functions, implementation of a modification of this sort in FASOM would involve some essentially arbitrary assumption about the form and sensitivity of utility to aspects of the timber stock. An example of such an approach in the context of intertemporal harvest decisions is given by Max and Lehman (1988).

Expanded geographic range of timber management investment simulation—Extensions of the timber investment component in FASOM that would allow more detailed modeling include simulation of intensified timber management options for (a) hardwoods and (b) softwoods in regions outside the South and PNWW. This would require development of a regional-level database describing the associated timber yields and costs. Current timber management options in FASOM are dictated by regional-level estimates available from ATLAS-based inputs used in the 1993 RPA timber assessment update (Haynes and others 1995).

Adding additional market levels—The TAMM model, on which certain features of the forest sector in FASOM are based, is a two-level model that includes both a set of regional stumpage markets and a set of regional primary product markets for the most important primary products (Adams and Haynes 1980, in press). In FASOM, this structure is collapsed into a single market for log products (saw logs, pulpwood, and fuelwood). This was done as a practical consideration, because adding more market levels increases the complexity and size of the model, although if the translation from two into a single set of markets is done correctly, all the information contained in the original demand curves ought to be preserved. What is lost in this process is the ability to trace the fate of carbon in products, such that the distribution of products is based on economic behavior and the ability to simulate an array of policies based in other portions of the market continuum from stumpage to final consumer. In the current version of FASOM, the distribution of products manufactured from logs is fixed at the mix implicit in the HARVCARB model and so does not change from scenario to scenario. It would be preferable to have the model, itself, solve for this mix of products in primary markets and allow the carbon fate analysis to differ as the mix changes.

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Appendix A: Scope of the ASM Version in FASOM

This appendix documents the basic assumptions and elements regarding the agricultural sector model (ASM) of the United States that is currently residing in FASOM. Various versions of the ASM have been and are being used to investigate the economic impacts of technological change, trade policy, commodity programs, introduction of new products, environmental policy, and global warming on the U.S. agricultural sector (Adams and others 1986, 1993; Baumes 1978; Burton and Martin 1987; Chang and others 1991, 1992, 1993; Chattin 1982; Coble and others 1992; Hamilton 1985; Hickenbotham 1987; House 1987; Tanyeri-Abur 1990; Tyner and others 1979). Direct incorporation of the ASM model within FASOM for project purposes was preferable to representing the agricultural sector through carbon sequestration supply curves, which would capture the relation among (a) welfare, (b) the amount of carbon that could be sequestered, and (c) the area required to sequester that carbon. The supply curves would depend, however, on policy variables that could change from run to run. This would have necessitated development of a large number of supply curves before running the model for policy analysis purposes.

Conceptually, the ASM is a price-endogenous mathematical programming framework following the spatial equilibrium concept developed by Samuelson (1952), extended by Takayama and Judge (1971), and reviewed by McCarl and Spreen (1980) and Norton and Schiefer (1980). The model was originally designed to simulate competitive equilibrium solutions under a given set of demand and supply conditions. The objective function is the summation of all areas beneath product demand curves minus the summation of all areas beneath import and factor supply curves; that is, the area between the demand and supply curves to the left of their intersection. This area is also referred to as "producers' and consumers'" surplus in the economic literature. This objective function represents a social welfare function measuring the benefits for producers and consumers from producing and consuming the agricultural commodities. The production and consumption sectors are made up of many individuals operating under competitive market conditions. When the sum of producers' plus consumers' surpluses is maximized, the model solution represents an intersection of supply and demand curves and, thus, simulates a perfectly competitive market equilibrium. Prices for all factors of production and outputs therefore are endogenously determined by the supply and demand relations of all commodities in the model.

The objective function contains a nonlinear portion that represents the area under the demand curves for agricultural and forest products. In FASOM, demand for agricultural products is characterized by constant elasticity demand functions, and demand for forest products is characterized by linear functions. The linear portion of the objective function includes the costs associated with producing, managing, harvesting, and selling agricultural and forest products in the various regions in the model. This equation appears in the FASOM NLP formulation with terms for each type of variable for each decade, weighted by the discount rate. The agricultural objective function is weighted by a factor reflecting the harvest of agricultural products each year during a decade. This factor equals the sum of the present value factors over 10 years. Furthermore, the last decade is weighted by a factor equaling the future value of an infinite stream, thereby providing the terminal conditioning for land remaining in agriculture.

The agricultural sector model component is designed to simulate the effects of various changes in agricultural resource use or resource availability, which in turn determines the implications for prices, quantities produced, consumer's and producer's welfare, exports, imports, and food processing. The model considers production, processing, domestic consumption, imports, exports, and input procurement. The model distinguishes between primary and secondary commodities; primary commodities are those directly produced by the farms and secondary commodities are those involving processing. For production purposes the United States is divided into 63 geographical subregions. Each subregion has different endowments of land, labor, water, and crop yields. Therefore, the disaggregated information also is an important feature in this model. The supply sector of the model works from these regional input markets and a set of regional budgets for a number of primary crops and livestock and a set of national processing budgets, which use these inputs. There also are import supply functions from the rest of the world for several commodities. The demand sector of the model reflects the intermediate use of all the primary and secondary commodities, domestic consumption use, and exports. Details on these items follow.

Primary Commodities

There are 33 primary commodities in the model, which are listed in table 1. The primary commodities are chosen to depict the majority of total agricultural production, and use, and economic value. They can be grouped into crops and livestock.

Table 1—Primary commodities modeled in FASOM

No.	Crop commodity	Units[a]	No.	Livestock commodity	Units[a]
1	Cotton	Bales	14	Milk	Cwt
2	Corn	Bushel	15	Cull dairy cows	Head
3	Soybeans	Bushel	16	Cull dairy calves	Head
4	Wheat	Bushel	17	Cull beef cows	Cwt, LW
5	Sorghum	Bushel	18	Calves	Cwt, LW
6	Rice	Cwt	19	Yearlings	Cwt, LW
7	Barley	Bushel	20	Nonfed beef	Cwt, LW
8	Oats	Bushel	21	Fed beef	Cwt, LW
9	Silage	Ton	22	Veal calves	Cwt, LW
10	Hay	Ton	23	Cull sows	Cwt, LW
11	Sugar cane	1000 pounds	24	Hogs	Cwt, LW
12	Sugar beets	1000 pounds	25	Feeder pigs	Cwt, LW
13	Potatoes	Cwt	26	Poultry	GCAU
			27	Cull ewes	Cwt, LW
			28	Wool	Cwt
			29	Feeder lambs	Cwt, LW
			30	Slaughter lambs	Cwt, LW
			31	Unshorn lambs	Cwt, LW
			32	Wool subsidy	$
			33	Other livestock	GCAU

[a] Cwt = hundred weight; LW = live weight; GCAU = grain-consuming animal unit.

Both supply and demand information (that is, prices, quantities, slopes, elasticities) are required in the model. The total supply consists of domestic production from all agricultural regions and imports. Total demand is made up of domestic and foreign (or export) components. Domestic demand includes food consumption, commodity credit corporation stock, and livestock feed and processing. Transportation costs to the market are included in the supply budget. Livestock feed and processing demands are endogenously determined. The prices and quantity data came from *Agricultural Statistics* (USDA National Agricultural Statistics Service 1994), *Agricultural Prices* (USDA National Agricultural Statistics Service 1995a), and *Livestock and Poultry Situation and Outlook Report* (USDA Economic Research Service 1995b). Elasticity, slope, and other information came from Baumes (1978), Burton (1982), Tanyeri-Abur (1990) and House (1987).

Secondary Commodities

The model incorporates processing of the primary commodities. The production of primary commodities are regionally specified, but the processing of secondary commodities is done in the overall U.S. aggregate sector. Table 2 lists the 37 secondary commodities processed in the model. These commodities are chosen by their links to agriculture. Some primary commodities are inputs to the processing activities yielding these secondary commodities, and certain secondary products (feed and byproducts) are in turn inputs to agriculture. The primary data sources were *Agricultural Statistics* (USDA National Agricultural Statistics Service 1994), *Agricultural Prices* (USDA National Agricultural Statistics Service 1995a), *Livestock and Poultry Situation and Outlook Report* (USDA Economic Research Service 1995b), and *Livestock Slaughter* (USDA National Agricultural Statistics Service 1995b).

National Inputs

The model contains 24 national inputs (table 3). These generally are specified in dollar terms; for example, $10 worth of nitrogen, $20 worth of repairing cost. By doing so, the input use is converted into a homogeneous commodity. These inputs are usually assumed infinitely available at fixed prices, and the prices are updated annually according to the paid-by-farmers index in *Agricultural Statistics* (USDA National Agricultural Statistics Service 1994).

Regional Disaggregation

The model operates with the 11-region FASOM disaggregation. The data from the full 63-region version of ASM are aggregated to this basis.

Regional Inputs

There are four inputs available at the regional level: water, animal unit month (AUM) grazing, land, and farm labor. Production of crops and livestock compete for these scarce resources in each region; therefore, the price and quantities of these inputs are determined regionally. Two major types of land are specified. The first one (type 1) is land suitable for crop production. Type 2 land is suitable for pasture or grazing. The availability of these two types of lands was derived from *Agricultural Statistics* (USDA National Agricultural Statistics Service 1994). The regional prices of these lands were derived from the information in *Farm Real Estate Market Developments* (for example, USDA Economic Research Service 1981). Cash rental prices of land were used to reflect annual opportunity costs to the owners.

Table 2—Secondary commodities modeled in FASOM

No.	Crop commodities	Units[a]	No.	Livestock commodities	Units[a]
1	Soybean meal	Cwt	25	Fluid milk	Cwt
2	Soybean oil	1000 pounds	26	Skim milk	pounds
3	Raw sugar	1000 pounds	27	Nonfat dry milk	pounds
4	Refined sugar	1000 pounds	28	Cream	pounds
5	Corn starch	1000 pounds	29	Butter	pounds
6	Corn gluten feed	1000 pounds	30	Ice cream	pounds
7	Corn oil	1000 pounds	31	American cheese	pounds
8	Ethanol	1000 pounds	32	Other cheese	pounds
9	HFCS[b]	1000 pounds	33	Cottage cheese	pounds
10	Corn syrup	1000 pounds	34	Fed beef	Cwt,CW
11	Dextrose	1000 pounds	35	Nonfed beef	Cwt,CW
12	Confectioneries	1000 pounds	36	Veal	Cwt,CW
13	Beverages	1000 pounds	37	Pork	Cwt,CW
14	Baked goods	1000 pounds			
15	Canned goods	1000 pounds			
16	Dried potatoes	Cwt			
17	Chipped potatoes	Cwt			
18	Frozen potatoes	Cwt			
19	Feed grains	1000 pounds			
20	Dairy protein feed	1000 pounds			
21	High protein swine feed	1000 pounds			
22	Low protein swine feed	1000 pounds			
23	Low protein cattle feed	1000 pounds			
24	High protein cattle feed	1000 pounds			

[a] Cwt = hundred weight, CW = carcass weight.
[b] HFCS = high fructose corn syrup.

The supply of grazing land is divided into public and private ownership. Grazing on public land is available at a constant price, and grazing on private land can be obtained by an upward-sloping supply schedule. Information on public grazing comes from the *Grazing Statistical Summary* (USDA Forest Service 1994). Private grazing information comes from estimates in Joyce (1989). Information on grazing fees originates from *Estimating Forage Values for Grazing National Forest Lands* (Hahn 1989).

The labor input also include two components: family labor and hired labor. The model requires specification of a maximal amount of family labor available and a reservation wage for family labor. The additional labor hired is based on an inducement wage rate, which is higher than the reservation wage. The regional information about the quantities and wages was obtained from the USDA Economic Research Service (1995a).

Table 3—National inputs modeled in FASOM

No.	Inputs	Units[a]
1.	Nitrogen	
2.	Potassium	
3.	Phosphorous	
4.	Lime	
5.	Other chemicals	
6.	Custom operation	
7.	Seed costs	
8.	Fuel and energy costs	
9.	Interest on operating capital	
10.	Irrigation energy cost	
11.	Repair costs	
12.	Vet and medical costs	
13.	Marketing and storage costs	
14.	Insurance (except crop)	
15.	Machinery	
16.	Management	
17.	Land taxes	
18.	General overhead costs	
19.	Noncash variable costs	
20.	Crop insurance	
21.	Land rent	
22.	Set-aside (conservation cost)	
23.	Processing labor	
24.	Other variable costs	

[a] All units are U.S. dollars.

The water input also is divided into fixed (or surface) and variable available (or pumped ground) water and is supplied. The fixed water is available for a constant price, but the amount of variable water is provided according to a supply schedule where increasing amounts of water are available for higher prices. The information on water came from USDA and National Agricultural Statistical Services sources who used the *Farm and Ranch Irrigation Survey* (U.S. Department of Commerce, Bureau of Census 1988) and other government sources in its formation.

Regional Production Activities

Currently more than 200 production possibilities (budgets) are specified to represent agricultural production. These include major field crop production, livestock production, tree production, and some miscellaneous transfer activities. Some field crop activities also are divided into irrigated and nonirrigated according to the irrigation facilities available in each region.

In some cases, the production possibilities produce more than one commodity. All commodities are produced by more than one production possibility. Most field crops (except rice) are produced by either irrigated or nonirrigated production practices. Livestock production is somewhat more complicated. The model solves for the number of livestock reared. Livestock production uses land labor and feedstuffs, and produces both final products (animals for slaughter) and intermediate products (calves for feeding). These variables are defined by decade, region, type of animal, and livestock technology choice. The livestock variables reflect production of multiple products. AUMs of grazing are supplied via a two-part structure. The first part refers to the state and Federal land supplies through such agencies as the Bureau of Land Management and USDA Forest Service. This land is available at a fixed rental rate up to a maximum. Table 4 lists the main types of production activities and details the relation between production activities and primary commodities.

For each activity, information on yields and uses of national and regional inputs or other commodities is required. The basic source of this information is the USDA Economic Research Service (1982). The irrigated vs. nonirrigated budget breakdown arose from the USDA water group that developed budgets based on the Federal Enterprise Data System (FEDS) sources, the survey of irrigated acreage, extension budgets, and Soil Conservation Service budget sets.[1] The yields in all the crop budgets were updated annually according to *Agricultural Statistics* (USDA National Agricultural Statistics Service 1994). The livestock budgets came straight from the FEDS system (USDA Economic Research Service 1982).[2] Some of their yields also could be updated by the information available in *Agricultural Statistics* (USDA National Agricultural Statistics Service 1994).

Processing Activities

The secondary commodities are produced by various processing activities: soybean crushing; corn wet-milling; processing of potatoes, sweeteners, and timber; combining feed ingredients into various livestock and poultry feed; and converting livestock and milk into consumable meat and dairy products. Processing cost of each commodity is calculated as the difference between its price and the costs of the primary commodity inputs. A list of the processing activities is given in table 5.

Soybean crushing converts soybean meal and oil. Two soybean crushing activities are included so that the model can select the more profitable one. The meat processing converts culled animals to slaughter and slaughter to meat. The dairy processing converts raw milk to five different dairy products. The feed alternatives involve multiple processing activities so that the model can select the least cost combination of feed ingredients.

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[1] Thanks to Bob House, Marcel Aillery, Glen Schaible, and Terry Hickenbotham in the USDA Economic Research Service Policy and Soil and Water Groups for making these data available.

[2] Thanks to Bob House and Terry Hickenbotham for making these data available.

Table 4—Production activities and primary commodities modeled in FASOM

Production activities	Primary commodities
Crop production:	
Cotton	
Cotton irrigated	Cotton
Corn	
Corn irrigated	Corn
Soybeans	
Soybeans irrigated	Soybeans
Wheat	
Wheat irrigated	Wheat
Sorghum	
Sorghum irrigated	Sorghum
Rice irrigated	Rice
Barley	
Barley irrigated	Barley
Oats	
Oats irrigated	Oats
Silage	
Silage irrigated	Silage
Hay	
Hay irrigated	Hay
Sugar cane	
Sugar cane irrigated	Sugar cane
Sugar beets	
Sugar beets irrigated	Sugar beets
Potatoes	
Potatoes irrigated	Potatoes
Livestock production:	
Beef cow	Cull beef cows, beef feeder yearlings, live calves
Beef feed	Slaughtered fed beef cows
Cow calf	Cull beef cows, live calves, beef feeder yearlings
Dairy	Milk, cull dairy cows, live calves
Farrow finishing	Hogs for slaughter, cull sows
Feeder pig	Feeder pigs, cull sows
Feedlot	Slaughtered fed beef cows
Hog farrow	Hogs for slaughter, cull sows
Pig finishing	Hogs for slaughter
Other livestock	Other livestock (primary horses)
Poultry	Poultry
Sheep	Slaughtered lambs, feeder lambs, culled ewes, wool, wool incentive payments, unshorn lamb payments
Stocker	Live (beef feeder) calves, slaughtered nonfed beef

Table 5—Processing activities modeled in FASOM

Processing activities	Number of activities
Soybean crushing:	
Soybean to soybean meal and oil	2
Livestock to meat and dairy products:	
Culled beef cow to nonfed slaughter	1
Culled dairy cow to nonfed slaughter	1
Beef feeder yearling to nonfed slaughter	1
Nonfed slaughter to nonfed beef	1
Live calf to calf slaughter	1
Culled dairy calf to calf slaughter	1
Calf slaughter to veal	1
Fed slaughter to fed beef	1
Hog slaughter to pork	1
Sow slaughter to pork	1
Raw milk to skim milk and cream	1
Raw milk to fluid milk and cream	1
Raw milk to butter and nonfat dry milk	1
Cream and skim milk to American cheese	1
Cream and skim milk to other cheese	1
Cream and skim milk to ice cream	1
Cream and nonfat dry milk to ice cream	1
Cream and skim milk to cottage cheese	1
Livestock Feed Mixing:	
Feed grain	6
Dairy protein feed	6
High protein swine feed	1
Low protein swine feed	2
High protein cattle feed	1
Low protein cattle feed	4
Potato processing:	
Potatoes to frozen potatoes	1
Potatoes to potato chips	1
Potatoes to dehydrated potatoes	1
Corn wetmilling:	
Corn to corn-oil, gluten feed, and starch	1
Gluten feed to soybean meal	1
Starch to HFCS[a]	1
Starch to corn syrup	1
Starch to dextrose	1
Starch to ethanol	1
Sweetener processing:	
HFCS and refined sugar to beverages	1
HFCS and refined sugar to confectioners	1
HFCS and refined sugar to canned good	1
HFCS and refined sugar to baked good	1
Sugar cane to cane-refinering	1
Cane-refinering to refined sugar	1
Sugar beets to refined sugar	1

[a] HFCS = high fructose corn syrup.

Crop Mixes

The sector model is divided into 63 regions, and within each region, individual crop production often is represented by one budget. Such representation cannot capture the full factor-product substitution possibilities in each of those areas, and in some cases, this can lead to quite misleading results. This is avoided by requiring the crops in a region to fall within the mix of crops observed in historical crop records (USDA National Agricultural Statistics Service 1994). The model is constrained so that the crop mix for each area falls within one of the mixes observed in the past 20 years. These variables help resolve the aggregation problem as explained in McCarl and others (in press). There could be some concern in using the crop mixes for all projection years and thus they are dropped after the first 20 years.

Government Farm Programs

Variables reflect government payments for farm program provisions involving the 50/92 provision (Chang and others 1992), diverted acres unharvested production, and production below farm program yield. The model does not reflect an actual commodity produced under these features, because acreage is diverted from production and farmers are paid for foregone production. These are defined for each decade and commodity that the farm program is active in. In the present model, the 1990 farm program is in place only for the 1990s decade.

Tableau Information

A tabular overview of the agricultural component of FASOM *for a single region* is given in simplified form in table 2 (in text). The columns in this table represent variables, and the rows represent equations (for example, resource constraint). If the value of one of the variables is zero, information is provided that shows what it would cost society, in terms of the change in consumers' and producers' surpluses, to force one unit of that activity into the objective function. This value is sometimes referred to as the "opportunity cost" of a variable. The agricultural model contains 19 types of variables: (a) three forestry variables, (b) transfer land from forestry, (c) transfer land to forestry, (d) program crop production, (e) nonprogram crop production, (f) livestock production, (g) crop mix, (h) livestock mix, (i) land supply, (j) water supply, (k) labor supply, (l) input purchase, (m) processing, (n) domestic demand, (o) export demand, (p) import supply, (q) Commodity Credit Corporation loan, (r) deficiency payments, and (s) other farm program payments. Nineteen equations in the agricultural portion of FASOM include the objective function and 18 constraints. More detailed descriptions of the variables and equations are provided by Adams and others (1994).

The model has three sets of terminal conditions: (a) the terminal inventory of private timberland, (b) agricultural lands in the terminal period, and (c) log-processing capacity in the terminal period. Terminal conditions applied to agricultural lands and forest processing capacity have a slightly different rationale. These conditions are added primarily for valuing these entities in a consistent intertemporal framework. Agricultural lands in the next-to-last decade are treated as if they stay forever in their terminal use. Agricultural returns and costs in that decade are multiplied by a factor treating them as an infinite stream. Finally, forest processing capacity at the end of the projection period is valued at its replacement cost.

Timber inventory remaining at the end of a finite projection period should be incorporated in the objective function at the value that it would obtain if it were managed optimally in perpetuity (from the terminal time point onward). If all possible terminal inventory states were valued in this way, the infinite horizon harvest problem would involve (in the spirit of Bellman's [1957] principle of optimality) choosing the optimal path from a fixed starting point (the current inventory) to one of the several terminal inventory states, so as to maximize the sum of transition and terminal values. Valuing, or approximating the value of, the terminal states would be aided if they could be characterized in some general way. If all external conditions are held constant after some point, available theoretical studies generally concur that convergence to some form of equilibrium (fixed cycles or even flow) is to be expected, but it is difficult to be more specific except in special cases.

If, as in the case of FASOM, policy concern is limited to the first five decades of the projection, a practical solution is to adopt some approximation for terminal inventory valuation and extend the projection period to the point where the discounted contribution of the terminal state is so small that it does not significantly influence the results in the period of interest. This is the approach taken here. For any given terminal inventory volume, an associated perpetual periodic harvest volume is computed assuming the inventory is fully regulated. We used von Mantel's formula (Davis and Johnson 1987) simplification for this purpose. Rotation ages for this calculation were drawn from harvest ages observed in the FASOM solution in the decades prior to termination.[3] The value of this regulated flow was computed as consumers' surpluses from the demand curves of the last decade (2080s), less all associated costs of harvest, management, and transport with appropriate discounting adjustments.

[3] The simplification (see Davis and Johnson 1987) assumes a linear yield function so that in a forest fully regulated on a rotation of R years, the annual harvest volume would be determined as twice the growing stock divided by the rotation age. A fully regulated forest has an equal number of acres in each age class from regeneration through rotation age and can produce an even flow of volume in each year through harvesting of just the oldest (rotation age) class. This target structure seems a reasonable terminal approximation.
Our choice of rotation should approximate the so-called Faustmann rotation age, and numerous studies have been done that demonstrate the optimality of the Faustmann rotation for a fully regulated, steady state forest in the long run (for example, Brazee and Mendelsohn 1988, Heaps 1984, Hellston 1988, and Lyon and Sedjo 1983). As noted above, however, clear demonstration that an optimal harvest trajectory leads directly to full regulation of the forest on a Faustmann rotation in the long run has proven elusive (see Mitra and Wan 1985, 1986).

Appendix B: Data Used for the Forestry Sector

This appendix contains detailed information on (a) general makeup of the forest sector portion of the model and definitions, (b) data formats and data sources for the forest sector portion of the model, including timber growth and yield and timber management costs, and (c) treatment of land use changes involving the forest sector.

General Format and Definitions

The first-generation FASOM model was developed by using the strata presented in figure 3 to describe the private timberland base.

Land suitability class (CLS)—The five land suitability classes are:

1. FORONLY—Includes timberland acres that are not converted to agricultural uses.

2. FORCROP—Includes acres that begin in timberland and that can be converted to crop.

3. FORPAST—Includes acres that begin in timberland and that can be converted to pasture.

4. CROPFOR—Includes acres that begin in crop and that can be converted to timberland.

5. PASTFOR—Includes acres that begin in pasture and that can be converted to timberland.

Owners—FASOM includes two different private, forest owner groups: forest industry (FI) and other private (OP). The traditional definitions are used, where industrial owners possess processing capacity, and other private owners do not.[1]

Species—FASOM employs four different species types:

1. SOFSOF—Softwood forest type in current and subsequent model periods.

2. HARHAR—Hardwood forest type in current and subsequent model periods.

3. HARSOF—Hardwood forest type that is naturally regenerated or replanted to softwood type.

4. SOFHAR—Softwood forest type that is regenerated or replanted to hardwood type.

Site—FASOM includes three different site classes, as measures of forest productivity:

1. HIGH—High site-productivity group.

2. MEDIUM—Medium site-productivity group.

3. LOW—Low site-productivity group.

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[1] Unlike Powell and others (1993), the other private inventory in FASOM does not include Native American lands. Harvests from these lands are included with the other public exogenous harvest group.

The site groups were defined based on ATLAS inputs from the 1993 RPA update (Haynes and others 1995). Productivity ranges can differ by region. For the South, the HIGH site group produced at least 85+ cubic feet per acre per year at culmination of MAI (mean annual increment). The MEDIUM site group produced 50-84 cubic feet per acre per year, and the LOW site group produced 20-49 cubic feet per acre per year. In the PNW region, the site groups were defined for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and other species. For western hemlock, the HIGH site group can produce at least 225+ cubic feet per acre per year at culmination of MAI; the MEDIUM site group can produce 120-224 cubic feet per acre per year, and the LOW site group can produce 20-119 cubic feet per acre per year. For all other species, the HIGH site group produced at least 165+ cubic feet per acre per year; the MEDIUM site group 120-164 cubic feet per acre per year; and the LOW site group 20-119 cubic feet per acre per year. Yields can differ markedly by site groups, and any refinements in FASOM classification of site ratings will depend heavily on related developments in the handling by ATLAS of productivity measures.

Management intensity classes (MIC)—FASOM has four different management classes or regimes that dictate how cohorts are managed in the model:

1. LO-LO—Lowest management intensity class, or "passive;" assumes no management intervention of any kind between harvests of naturally regenerated aggregates.

2. LO—Low management intensity class; assumes custodial management of naturally regenerated aggregates. Timberland receives a low level of timber management such as forest protection and elimination of grazing by livestock.

3. ME—Medium management intensity class; assumes minimal management in planted aggregates.

4. HI—High management intensity class; assumes genetically improved stock, fertilization or other intermediate stand treatments in planted aggregates.

Specific practices can differ by region, site quality, and forest type. The LO, ME, and HI MICs were derived from ATLAS management intensity classes from the 1993 RPA assessment update (Haynes and others 1995).

In all regions outside the South or PNWW, ATLAS places all timberland acres in the equivalent of the LO MIC, thereby assuming that all acres are naturally regenerated and receive no significant intermediate treatments before final harvest. Likewise, in the regions outside the South and the PNWW, ATLAS currently uses only one aggregate site class.

The LO-LO MIC was added to the ATLAS-based MICs to represent future harvested acres that are totally passively managed, where the owner accepts whatever type and rate of regeneration occurs naturally. Future merchantable timber yields for the LO-LO MIC are lagged by 10 years compared to the LO MIC, and LO-LO yields are some proportion of the LO timber yields for that same site class and forest type, depending on the region.

Products—The following forest products (PRODS) are defined:

1. SAWTSW—Softwood sawtimber products.
2. PULPSW—Softwood pulpwood products.
3. FUELSW—Softwood fuelwood products.
4. SAWTHW—Hardwood sawtimber products.
5. PULPHW—Hardwood pulpwood products.
6. FUELHW—Hardwood fuelwood products.

The allocation of products can differ by region, forest type, site class, MIC, and age class. The estimates were obtained from the regional FIA (USDA Forest Inventory and Analysis) units, with most based on analysis of available FIA data and expert opinions of analysts in each region. The product allocations by age class and other descriptors are one set of model inputs that warrant more attention in future studies for empirical verification.

In the present model, we use a single "national" market to represent what is in fact a set of regional markets for the products described above. For both saw logs and pulpwood, national price is taken as the highest of the regional average prices observed during the 1980s (Adams and others 1996). The transport costs are the average differences between this national and other regional prices. We assumed these differences would change over time and relatively by region in parallel with processing costs contained in Haynes and others (1995). Because all transactions are measured "at the mill" or in "mill delivered" terms, intraregional log haul costs are included in prices. Demand equations for saw logs for the five initial decades of the projection were derived from TAMM by summing regionally derived demand relations for saw logs (with prices adjusted to the national level). Demand elasticities ranged between -0.34 and -0.44 for softwood and -0.19 and -0.22 for hardwood. Pulpwood demand relations were derived from the basic NAPAP roundwood consumption and price projections, assuming a linear demand approximation and a demand elasticity of -0.4. In this manner, the projected log demand equations reflect the specific log processing technology assumptions incorporated in the RPA update analysis (Haynes and others 1995) as well as the underlying product demand and macroeconomic forecasts. Demand projections for different assumptions on technology trends or demand determinants (as in sensitivity analyses) were derived from appropriate projections of TAMM and NAPAP. In addition, for any given policy scenario (for example, public cut) the evolution of product demand is likely to differ with trends in prices of forest products and substitutes in a manner unique to that scenario. We approximate this dynamic development of log demand by rerunning the TAMM and NAPAP models with the appropriate scenario input to obtain revised demand equation projections.

Data Format and Sources

The sources and format of associated data representing forest inventory, timber yields, and timber management costs in FASOM are discussed next. To provide perspective, 358 million acres of private timberland existed in the United States in 1992 (Powell and others 1993). One-half of the private timberland acres are in the South. In addition, 80 percent of the private timberland acres are held by other private owners, although a large percentage of forest land in the Pacific Northwest is owned by forest industry. Finally, hardwood species are the predominant forest species group in the East, and softwood species are the primary forest species group in the West.

Forest inventory—Inventory data representing the private timberland base consists of the area by strata described earlier (fig. 3) and the merchantable timber volume per acre. FASOM inventory data were derived from the ATLAS inventory estimates for the 1993 RPA update (Haynes and others 1995). The ATLAS data sets are based on over 70,000 inventory plots that are periodically remeasured on non-Federal timberlands by the regional FIA units (Powell and others 1993).

The ATLAS inventory data includes estimates of privately owned timberland (acres) and growing stock yields (cubic feet per acre) for each RPA region by age class, forest type, site class, and MIC.[2] Acres within ATLAS age classes were assigned to appropriate FASOM age cohorts. Acres by region that potentially could be converted from crop or pasture land to forest land were included in the CROPFOR and PASTFOR land classes, respectively, based on National Resource Inventory data of the USDA Soil Conservation Service (1989a). All other acres were assigned to the FORONLY land class.

In translating from ATLAS to FASOM data sets for the South, it was necessary to aggregate the 5-year age classes in ATLAS to the 10-year age classes used in the FASOM model. Weighted yields for each ATLAS age class within a FASOM age cohort were used for this purpose.

Timberland by region was classified by land class (CLS) using USDA Soil Conservation Service (1989a) National Resources Inventory estimates of other private forest land with medium or high potential for conversion to cropland and pastureland. Estimates of acres with medium or high potential for conversion to cropland and pastureland were entered in the FORCROP and FORPAST land classes, respectively. The FORCROP and FORPAST acres were assigned to FASOM high or medium site classes. All remaining timberland acres were assigned to the FORONLY land class. Nonstocked acres by region were entered in 0-9 age class.

[2] The FASOM starting inventory estimates by owner will not match those in Powell and others (1993) in some cases because (1) Native American lands are not included in FASOM's other private category, and (2) not all regional ATLAS files for the 1993 RPA assessment update were updated, as was done for the Powell and others (1993) report.

Forest yields—The FASOM model requires projections of yields for existing stands, reforested stands, and afforested lands. Note that no afforestation yields are given for the PNWW region owing to the assumption, discussed earlier, that the land base is in equilibrium between forest and agricultural use in this region. Data on existing stand and reforestation yields were obtained from the corresponding ATLAS inputs used in the 1993 RPA assessment update (Haynes and others 1995). The RPA data give yields per acre based on FIA plot data as well as base yield tables for each RPA region broken out by age class, forest type, site class, and timber management intensity class. In FASOM, all timber yields are assumed to remain constant after 90+ years, tied to the FASOM age cohort 90+. Minimum harvest ages in FASOM are drawn as well from the ATLAS inputs used in the 1993 RPA assessment update (Haynes and others 1995). Minimum harvest ages differ by region, owner, site group, forest type, and MIC.

Yields for afforested lands are derived from yield tables updated from Moulton and Richards (1990) and reconciled with Birdsey's (1992a) estimates. The afforestation yield estimates are given by region (defined in Moulton and Richards 1990) and forest type for both cropland and pastureland.

Yields for existing stands were developed by (a) deriving stocking ratio for each management unit (Mills and Kincaid 1992), (b) applying relative density change coefficients using full and half linear[3] approaches to normal equations as appropriate, and (c) estimating yields (cubic feet per acre) for existing stands by age class over time and using the following formula:

$$V_{i+1,t+1} = S_{i+1,t+1} * Y_{i+1}$$

where V = volume/acre for age class i+1 and time period t+1,

S = relative density change coefficient for age class i and time period t, and

Y = base yield for age class i+1.

Aggregate existing yields are broken out by softwood and hardwood components. Softwood percentages are derived from softwood percentage estimates given in the ATLAS MANAGE input file. In the South, softwood percentages for each management unit are determined in a manner similar to the weighted existing yields, with ATLAS age class softwood percentages aggregated into FASOM age cohorts. Softwood percentages are weighted based on the percentage of acres within each management unit and age class. Weighted softwood proportions[4] for each management unit are then aggregated by FASOM modeling cell. Weighted softwood proportions are arrayed by modeling cell and age cohort over time. Aggregate softwood and hardwood yields given by the FASOM modeling cell are the product of the aggregate existing yield estimates and the associated aggregate softwood (hardwood) percentage estimates by age cohort and time period.

[3] Quadratic form equations were used in the North Central regions (Lake States and Corn Belt).

[4] Note that hardwood percentages are derived as 1 -softwood percentage for each age and time period by FASOM land identification class.

Then, existing softwood and hardwood yields are broken out by softwood and hardwood products (sawtimber, fuelwood, and pulp) with the percentage of softwood and hardwood going to sawtimber, pulp, and fuelwood determined from estimates provided by USDA Forest Service FIA sources.[5] The percentage estimates were provided by fiber type (softwood or hardwood) and age cohort for each product in the model. The yield per acre for each product was derived by simply determining the product of the aggregated softwood (or hardwood) yields and the associated product percentages for each FASOM cell and age cohort over time.

In the first version of the model, time constraints led to several approximations pertaining to growth and yield and growing costs. Commercial thinning volumes were added to base yield volume estimates, starting at the age when thinning volumes first arise, in the two southern regions and the PNWW for derivation of existing and regenerated stand yield tables. Once again, these are the only three regions with timber management intensities other than LO.

Yields for existing and reforested stands in the LO MIC were derived from the base yield tables (including thinning), relative density change ("approach to normal") equations, and regeneration stocking ratios. Stocking ratios for existing stands for time period NOW were the ratio of plot yield to base yield table values by age cohort from the 1993 RPA assessment update (Haynes and others 1995) ATLAS input decks, and regeneration stocking ratios for regenerated stands (in the LO MIC) were derived from coefficients given in the ATLAS inputs.

Regenerated stand yields were derived from base yield tables from the 1993 RPA assessment update (Haynes and others 1995). For ATLAS management units with a LO MIC (naturally regenerated forests), yields were derived by using regeneration stocking ratios from ATLAS inputs. Stocking ratios for age cohorts 10 to 19, 20 to 29, and so forth, were derived by using "approach to normal" equations and the relative density change coefficients used in deriving FASOM existing stand yields. Aggregate regenerated stand yields for the LO MIC were the product of the weighted average of base yield table values for ATLAS management units within each corresponding FASOM cell and associated stocking ratios by age cohort. Aggregate yields were broken out by softwood and hardwood products to form the FORONLY, FORCROP, and FORPAST yields.

For regenerated stands with a ME or HI FASOM MIC, stands were assumed to be fully stocked (the stocking ratio for any age cohort was equal to 1). For these stands, the aggregate regenerated stand yields were simply the weighted average of base yield table values for ATLAS management units within each FASOM cell. The aggregate regenerated stand yields for the ME and HI MICs were then broken out by softwood and hardwood products.

Regenerated stand softwood and hardwood yields were determined by using the aggregate softwood or hardwood percentages used to derive existing stand softwood and hardwood yields. Regenerated stand product yields were derived by using the percentages used to develop existing stand yield tables. Regenerated stand yields for ages over 90+ were assumed constant. Regenerated stand yields were assumed to be equivalent for the FORONLY, FORCROP, and FORPAST land classes.

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[5] For example, USDA Forest Service, Southeastern Forest Experiment Station, Forest Inventory and Analysis (RWU 4801), P.O. Box 2680, Asheville, NC 28802.

Table 9—Forest types used to construct afforestation yields, FASOM

FASOM region	Forest type
Northeast	Red and white pine (*Pinus resinosa* Ait., *Pinus strobus* L.) Spruce (*Picea* A. Dietr.) Southern pine (Pinus spp.)
South Central	Southern pine (*Pinus* spp.)
Southeast	Southern pine (*Pinus* spp.)
Lakes States	Red and white pine (*Pinus resinosa* Ait., *Pinus strobus* L.)
Corn Belt	Mixed hardwoods (for example, *Quercus* L., *Acer* L.) Mixed softwoods (*Pinus* spp.)
Rocky Mountains	Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.)
Pacific Southwest	Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws)
Pacific Northwest-West side	Douglas-fir
Pacific Northwest-East side	Ponderosa pine

Afforestation yields were derived from Birdsey (1992a) and Moulton and Richards (1990). Birdsey gives yields (cubic feet per acre) by Moulton and Richards' (1990) region and forest type for crop and pasture land. These yields were assumed to represent the low FASOM site class. For the Southeast, South-Central, and PNWW regions, medium and high site class yields were determined by using inflation factors derived from ATLAS base yield tables for equivalent forest types by region. Forest types by region were determined by using Birdsey's (1992a) estimates of forest types planted by state, national tree planting data (USDA Forest Service 1992), and expert opinion. Forest types planted on marginal cropland and pastureland by region are given in table 6.

All afforested acres were assumed to be fully stocked in terms of ATLAS yield standards. Thus, yields were derived directly from Birdsey's (1992a) yield tables for those regions in which only one species was planted. Weighted afforestation yields were derived for the Northeast and Pacific Southwest (PSW) regions based on planting percentages by forest type given in Birdsey (1992b) and non-industrial private forest (NIPF) planting statistics (USDA Forest Service 1992). In addition, PSW afforestation yields for the low management intensity class were assumed to be 0.76 of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) yields in Birdsey's "Pacific" region. The "Pacific" region Douglas-fir yields were used to derive the FASOM PNWW region afforestation yields and the "Pacific" region ponderosa pine (Pinus ponderosa Dougl. ex Laws.) yields were used to derive FASOM PNWE afforestation yields. Cropland planted to forest was assigned a high FASOM site class, and acres planted on pastureland were assigned a medium site class.

Afforestation yields for FASOM age cohort "0 to 9" was the mean of Birdsey's age classes "0" and "5," and yields for FASOM age cohort "90+" were the average of Birdsey's age classes "95" and "105." Finally, afforestation yields were assumed constant after age cohort 90+.

No commercial thinning volumes were included in deriving afforestation yield tables. Afforestation yields for ME and HI MICs were derived by using ratios of ME to HI MIC yields for regenerated lands from ATLAS for the forest types assumed planted by region.

Afforestation softwood and hardwood yields were determined by using the softwood percentages used to derive existing stand softwood and hardwood yields.[6] Finally, afforestation product yields were derived from percentages used to develop existing stand yield tables. Afforestation yields are given for the land classes CROPFOR and PASTFOR.

Forestry cost estimates—FASOM cost tables were developed for major forestry activities. These activities include costs of stand establishment (including conversion costs associated with converting agricultural land to trees), intermediate treatment or maintenance, harvest and hauling of timber from a stand. Taxes were not included in the forestry costs to keep them consistent with cost accounting on the longer standing agricultural side of FASOM.

FASOM tables associated with forest establishment costs and intermediate management costs were derived from various data sources. Establishment costs include costs of site preparation, planting, and conversion (land clearing, wind rowing, burning), and intermediate management costs include costs of thinning, prescribed burning, timber cruising, road maintenance, and other costs. The management costs are decadal averages in the first-generation FASOM model.

Establishment costs differ by FASOM land class, with generally higher costs for reforested acres, such as those for FORONLY acres, and lower costs for afforesting CROPFOR and PASTFOR acres. A prohibitive cost estimate of 999.999 value was used to ensure that certain management options were not selected (such as LO MIC for afforestation, as currently configured).

Cost estimates also were assembled for converting timberland to cropland or pastureland. Sources were various Economic Research Service studies and expert opinion.[7] Most of the formal studies were dated, with most done mainly before 1980 and before significant changes in conversion technology, and so were augmented by expert opinion. To reflect different levels of conversion costs due to site, topography, drainage, and other factors, three levels of costs were used to represent a step

[6] In the FASOM Corn Belt region, softwood percentages suggested by Birdsey (1992a) were used to generate afforestation softwood and hardwood yields.

[7] Personal communication. March 1992. Bob Moulton, USDA Forest Service, State and Private Forestry, 14th & Independence, S.W., P.O. Box 96090, Washington, DC 20090-6090.

function or increasing marginal costs of conversion as more timberland is converted. Costs include that for land clearing, wind rowing, burning, and any necessary leveling and removal of large chunks for seedbed preparation. Any timberland converted to agricultural land is assumed to occur after harvest of any merchantable trees, and 75 percent of timber volume removed in land clearing is assumed to be hauled to market.

Any stand can be regenerated or converted to an agricultural use after harvest or at any time in its span of existence if it is grouped in the lowest management intensity class. The allocation selected is based on the net present value of the alternative uses (forest, crop, and pasture). In addition, the FASOM model will select among the alternative management intensities when it is regenerating a stand. As before, the most profitable option will involve consideration of supply and demand conditions, prices, yields, and costs. Yields associated with regenerated stands are arrayed by forest product, region, land class, owner, site class, management intensity, and age cohort. If a stand is converted to an agricultural use, it may be converted back to forestry in future time periods if it is more profitable to do so. Yields associated with such afforested stands are given for land classes CROPFOR and PASTFOR.

Land Use Changes Involving Forestry

The competition for land between the forestry and agricultural portions of FASOM, as well as the shift of some timberland to urban and developed uses, necessitates explicit considerations of pathways for land coming in and out of forestry in the FASOM modeling. Through the land class definitions used to describe the INVENTORY acres, described above, we identify other private timberland acreage that could potentially be converted to cropland and pastureland or, vice versa, agricultural land that could be shifted into forestry[8] (USDA Soil Conservation Service 1989b). Next, we look at FASOM constraints for land balance, interface between sectors, and land use limits.

Each region in FASOM possesses a different endowment of land and timber and crop yields. Nine regions are used to represent the productive land base in the forest and agriculture sectors: Northeast, Lake States, Corn Belt, Southeast, South Central, Rocky Mountains, Pacific Northwest Westside, Pacific Northwest Eastside, and Pacific Southwest. Two additional regions that contain insignificant timberland areas fill out the agriculture side: the Northern and Southern Great Plains. Total aggregate forest and agriculture area in the regions is fixed, and land migrates out at an exogenous rate to urban and developed uses (Alig and Wear 1992).

Land balances within sectors and movements between sectors in the FASOM model are controlled in three sets of constraints. Shadow prices of these constraints in a model solution give various elements of land values.

[8] The possibility of passive reverting of agricultural land to timberland is being considered for incorporation in a future version of FASOM. For example, idle agricultural land in some regions of the country would be a candidate to slowly revert to tree cover under certain circumstances. In those cases, timber yields on naturally reverting land would be discounted and lagged relative to naturally regenerated FORONLY yields.

We also constrain cropland-forestry land use shifts to the high site group, and pastureland-forestry shifts to the medium site group.[9] From the forestry side, the timber yields on land suitable for agriculture do not differ from those for the corresponding FORONLY cells. When forest land is shifted to agriculture, it is assumed that the timberland converted to cropland was in the high site group for other private timberland. Further, associated timber yields for actively afforested land are aligned with unique afforestation site ratings; for example, high site for afforested land has higher timber productivity than for high site FORONLY land.

Afforestation enrollments are placed into either the medium or high MICs depending on the FASOM relative profitability computations. By definition, afforested acres are precluded from being placed in the LO MIC because the afforested acres are assumed to be planted.

Converting between forestry and agricultural land uses takes place in FASOM when the present value of expected land rents in agricultural uses exceed those from timber growing, or vice versa. The accounting reflects constraints that only a specified percentage of other private timberland, by region, could be converted to cropland or pastureland over the 100-year FASOM horizon. When an afforested stand is harvested, the options for the next time period include replanting to obtain the same timber yields over the rotations as for the first afforested stand. In contrast, FASOM also has the option of placing the harvested afforested acreage into the LO MIC class, where natural regeneration at lower cost takes place. It logically would not enroll harvested afforested stands into the ME or HI MICs for FORONLY, because the timber management costs would be essentially identical to that for afforested land but with lower timber yields at corresponding ages. For the other private owner group, timber yields for timberland are potentially spread across five LANDCLASS categories; however, for FORONLY, FORCROP, and FORPAST,[10] the timber yields are identical for corresponding cells.

Constraints on the amount of timberland that could be converted to agricultural uses were derived from USDA Soil Conservation Service (1989a) data pertaining to other private forest land with medium or high potential for conversion to cropland and pastureland. The data were checked against that for prime farmland (defined in USDA Soil Conservation Service 1989b:21), representing forest, pastureland, cropland, rangeland, or other minor land uses that have good potential for cultivated crops (for example, slope less than 5 percent, not excessively eroded, no wetlands, and so forth). The published Soil Conservation Service data do not identify forest land qualifying as prime cropland below our FASOM region, thus allocation of prime cropland by forest type, MIC, and age cohort is by assumption (proportional to what is in the highest forestry site group).

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[9] A related assumption is that timberland acres cannot shift across site groups over the projection period; that is, acres remain in the same site group.

[10] The amount of rangeland suitable for tree planting is assumed to be insignificant, as is the amount of timberland likely to be converted to rangeland.

Exogenous land transfers—Two primary types of exogenous land transfers into and out of forestry in the current FASOM model are (a) tree planting due to government programs, and (b) transfers to urban and other developed uses. Tree planting due to government programs was enrolled each decade by region, for reforestation and afforestation. Estimates were based on RPA land base analyses (Alig and others 1990a, Alig and Wear 1992), tree planting reports from State and Private Forestry (for example, USDA Forest Service 1992), and personal communication with State and Private Forestry staff.

Projected exogenous levels of other private timberland converted to urban and developed uses were incorporated by region, based on considerations of projected changes in population and personal income (Alig and others 1990a). For forest industry, no net change in timberland area was assumed in this modeling phase. This means that the amount of other private timberland acquired by forest industry will offset the conversion of some forest industry land to urban and developed uses. Acres are assumed to exit the timberland base by age cohort in proportion to the total timberland area by age cohort.

Tableau Information

A tabular overview of the forestry component of FASOM *for a single region* is given in figure 4 (see text). The columns in figure 4 represent variables, and the rows represent equations. The tableau has been simplified, so it can be included on a single page and still convey the basic structure and features of the model. The tableau does not portray external product trade (import-export) activities or constraints, or show the data computations made within the GAMS code.[11]

The tableau represented in figure 4 depicts two time periods: now (t=0), 10 years from now (+10), and never. Management decisions are condensed into eight types of nonnegative variables. These appear as columns in the tableau. The variables represent (a) harvest existing stands, (b) reforest land after harvest, (c) transfer land to agriculture, (d) transfer land from agriculture, (e) use agricultural land, (f) transport forest products, (g) sell forest products by sale period, and (h) build processing capacity. The reduced tableau has 12 equations, 1 for the objective function and 11 representing constraints. If the variables fully use all the resource on the right side (RHS) of a specific constraint, then there will be a nonzero shadow price on the constraint. Adams and others (1994) provide more detailed information on the tableau components.

In its broad form, the forest sector of FASOM is a "model II" harvest scheduling structure as described by Johnson and Scheurman (1977) or a "transition" timber supply model as outlined by Binkley (1987). It is related to previous models of this sort as developed by Berck (1979) and to the timber supply model (TSM) developed by Sedjo and Lyon (1990). In both FASOM and TSM, the forest inventory is modeled in an even-age format by using a set of discrete age classes with endogenous decisions on management intensity, made at time of planting. Only a single demand region is identified and market interactions are restricted to the log level. The TSM is solved by using methods of optimal control with an annual time increment. FASOM, using a decade time step, is solved with nonlinear programming.

[11] The reader interested in a more detailed version of the tableau can contact the authors for a listing of the GAMS computer code for the 1995 version of FASOM.

Appendix C: FASOM File Structure

This appendix examines the structure and sequence of the files that make up the FASOM model. FASOM is implemented in the General Algebraic Modeling System (GAMS) (Brooke and others 1992). The model is made up of several files. This is done to allow separation of distinctly different types of data and to allow disciplinary experts to work on selected parts of the model.

The program can be divided functionally in several ways. The division we describe separates files into categories according to whether they involve data, data calculations, model specification, analysis execution, and report writing and model support, or both (fig. 9). Distinctions also are made among unifying files, forestry files, agricultural files, and carbon files. Additional details on file structure are provided by McCarl and others (1996), including operation of the five primary files.

Batch File Sequence and Control Switches

The basic method is to run six files, largely in sequence, by using a batch file, (Prefix).BAT. The files are run in the order given below. Figure 9 provides a flow chart of the model segments, with file names drawn from a 1995 version of the FASOM model, only for example purposes. File names in this publication are subject to change and may not reflect current labels.

ALLOFIT	Includes all agricultural, forestry, and carbon data as well as associated data calculations
FAMODEL	Defines the FASOM optimization model
FARPT	Set, alias, and parameter definitions for report writer
FAALTRUN	Causes the base model and the report writers to be run; policy experiments may be run by using FAAGTREE, FACARRUN, and FAALTRUN
FAFINAL	Prints a summary report of aggregate results comparing across the runs made
FACOMPUT	Saves scenario results in a GAMS-readable file (Results.Put), which may be used in addition to report writing

Users also may use an advanced basis in the case of problem cold starts; using the file FABAS, which writes that basis, and adding the statement INCLUDE "FABAS.BAS" in FAMODEL incorporates that basis.

FASOM contains three switches that alter the type of model being analyzed. These are set at the top of the FAMODEL but may be reset anywhere below that point. These switches and their functions are:

YESAG	A switch controlling whether the agriculture model is generated. A nonzero value activates the agriculture model and a zero value suppresses it.
YESFOR	A switch controlling whether the forestry model is generated. A nonzero value activates the forestry model and a zero value suppresses it. When both YESFOR and YESAG are nonzero, the full linked FASOM two-sector model is solved.
SEPFOR	A switch causing the separable model version to be generated for the forestry part of the problem, otherwise, a quadratic version is solved; this switch is implemented in the Forest only version.

File Functions and Sequence

As previously stated, there are five files executed by the batch file. These files call various associated files and control the model setup, solution, and output processes.

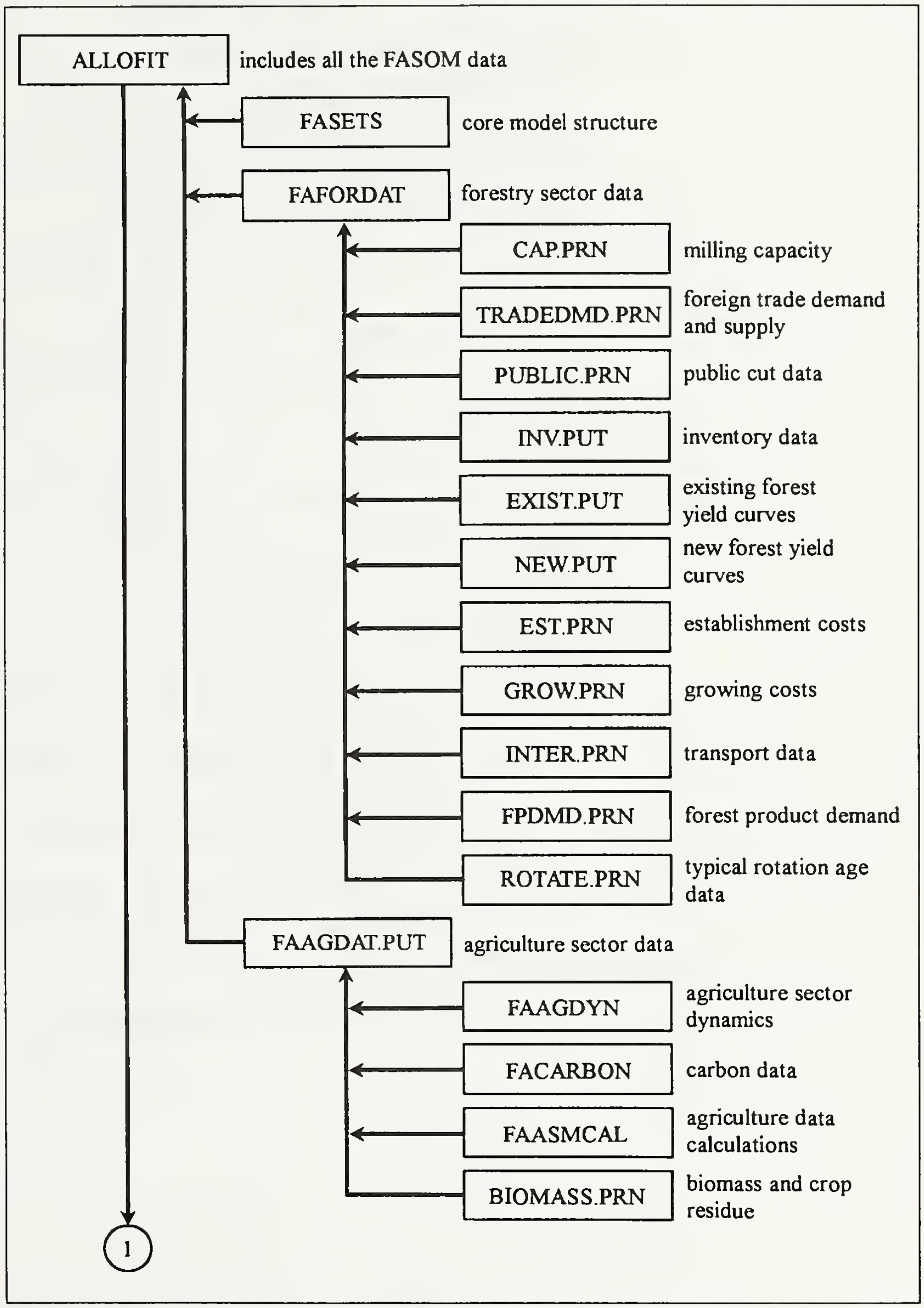


Figure 9—Files within FASOM and sequence of operation.

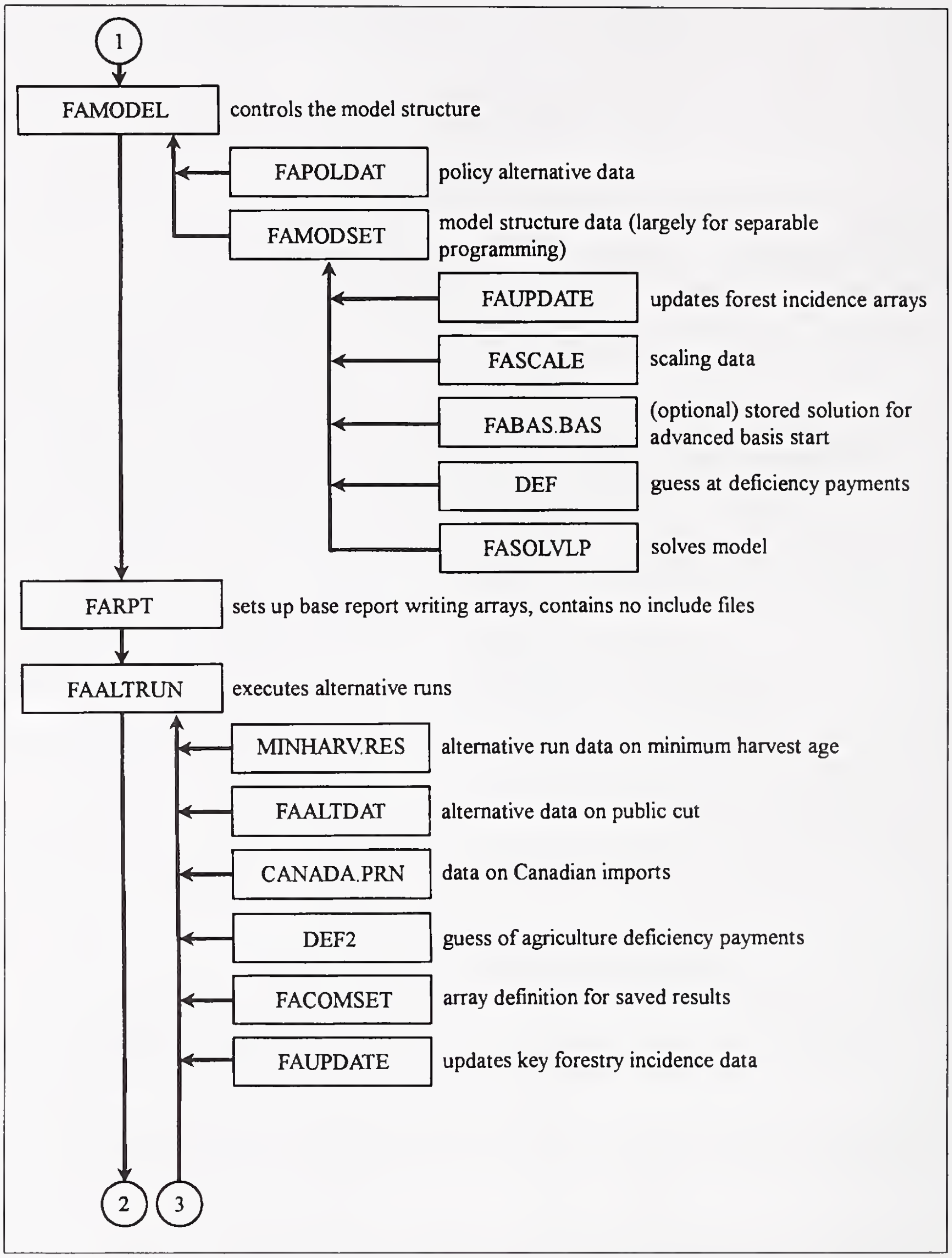
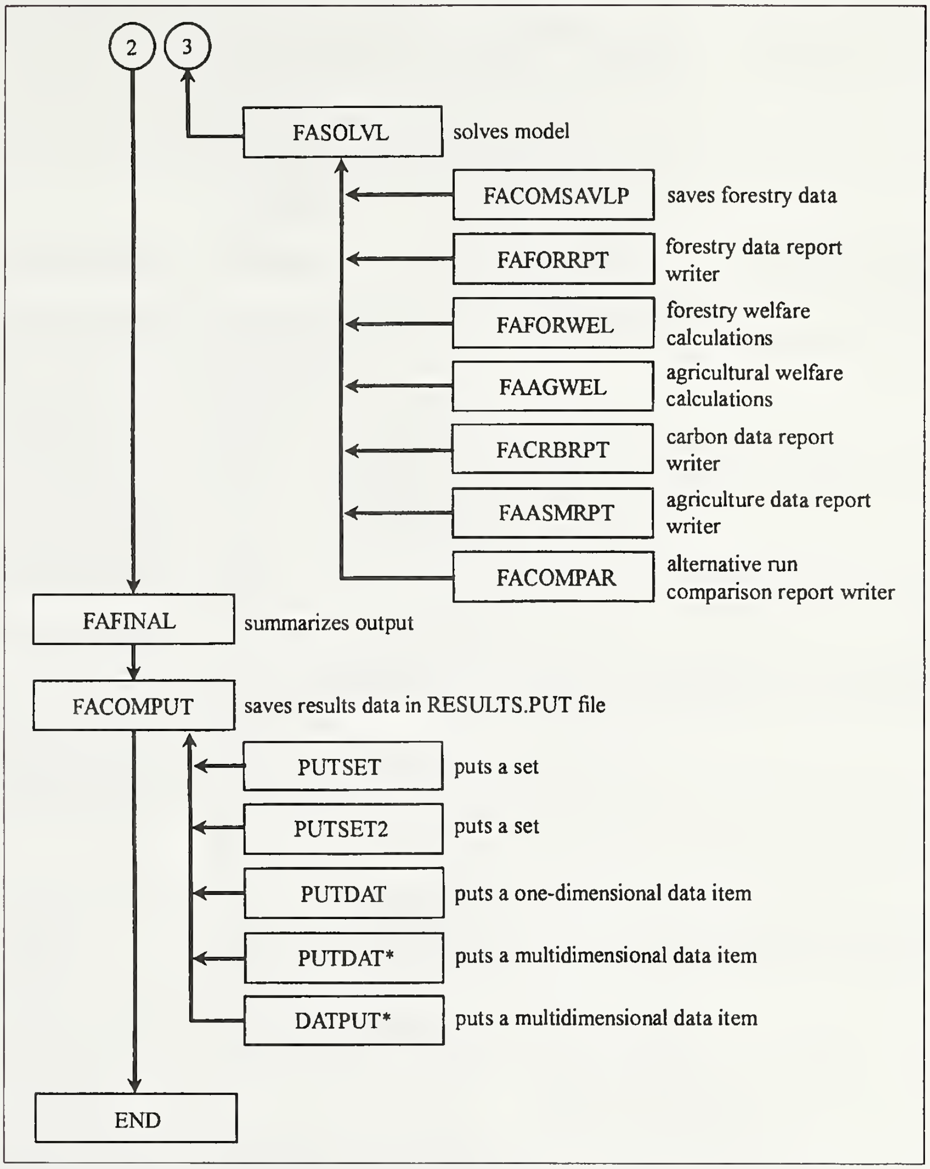


Figure 9—continued.


2
3
FASOLVL
solves model
FACOMSAVLP
saves forestry data
FAFORRPT
forestry data report writer
FAFORWEL
forestry welfare calculations
FAAGWEL
agricultural welfare calculations
FACRBRPT
carbon data report writer
FAASMRPT
agriculture data report writer
FACOMPAR
alternative run comparison report writer
FAFINAL
summarizes output
FACOMPUT
saves results data in RESULTS.PUT file
PUTSET
puts a set
PUTSET2
puts a set
PUTDAT
puts a one-dimensional data item
PUTDAT*
puts a multidimensional data item
DATPUT*
puts a multidimensional data item
END

Appendix D: FASOM Output File Contents

Summary FASOM output is produced in the FAFINAL.LST file by the GAMS instructions. Other output also appears in the alternative runs files (FABASRUN, FAAGTREE, FAALTRUN, FACARRUN) and in the detailed forest sector output file FAFORRPT. This appendix defines a number of the items appearing in these output files, and McCarl and others (1996) provide more details on output file items. Names of output file or items are subject to change, and the examples are drawn from a 1995 version of the FASOM model.

Combined Forest and Carbon Sector Output[1]

The following information is provided as output to the model:

FAWELFARE — The net present value of forest sector welfare, including consumers' surplus, producers' surplus, foreign interests surplus, returns to public cut, and terminal conditions. The units of this are in million dollars. The components of this table are:

DOMESTCON	Forest products domestic consumers' surplus
DOMESTPRO	Forest products domestic producers' surplus
PUBLICCUT	Public cut surplus, which actually is total revenue to public cut because public costs are not included.
DOMEST	Total of above three measures
ALLFOREIGN	Forest products surplus to foreign imports and exports. [Note: This is just foreign surplus because the curves are excess supply and demand relations and cannot be interpreted as consumers' or producers' surplus for particular parties.]
ALL	Total of DOMEST + ALLFOREIGN
TERMINAL	Consumers' surplus to the terminal conditions
GRAND	Total of ALL + GRAND—interpretable as total net present value of welfare

FAWELFAREP — Percentage changes in FAWELFARE from the base scenario. [Note: A 1.0 value means a 1-percent increase from the base.]

NETWELF — Net present values of total welfare less program costs. This has the GRAND data from the FAWELFARE table the net present value of subsidy incentive program costs (SIPCOST) based on data in the SIPCOST table and their difference (BOTTOMLINE=GRAND-SIPCOST).

NETWELFP — Percentage of change in NETWELF

PROGCOST — Program cost by decade and type of policy

[1] Carbon sector outputs include carbon associated with existing inventory processes, afforestation, and reforestation.

TIMBERINV	National timber inventory by decade in thousands of acres. This table also reports ownership, species, and management intensity class. The ownership classes are OP for other private and FI for industrial forests. The species are SOFSOF for softwood following softwood, HARSOF for softwood following hardwood, SOFHAR for hardwood following softwood, and HARHAR for hardwood following hardwood.
TIMBERINVP	Percentage of change in TIMBERINV
TIMBERHAR	National timber harvest by decade in thousands of acres. This table also reports ownership and species. The ownership classes and species are as above.
TIMBERHARP	Percentage of change in TIMBERHAR
CARBONINV	Metric tons of carbon in inventory by decade, in millions of tons
CARBONINV	Percentage of change in CARBONINV
REGCARBINV	Metric tons of carbon in inventory by decade and region, in millions of tons
TIMBPRICE	Forest product price in 1990 dollars per cubic foot by decade and product for pulpwood, sawtimber, and fuelwood from softwoods and hardwoods
TIMBPRICEP	Percentage of change in TIMBPRICE
TIMBPROD	Forest products production by decade and product in million cubic feet
TIMBPRODP	Percentage of change in TIMBPROD
TIMBCONS	Forest products consumption by decade and product probably in thousand cubic feet
TIMBCONSP	Percentage of change in TIMBCONS
CARBFLUX	Annual carbon addition in million metric tons per year
CARBFLUXP	Percentage of change in annual carbon addition
TIMBPROP	Timber producers price index relative to the base
TIMBPROQ	Timber producers quantity index relative to the base
TIMBCONP	Timber consumers price index relative to the base
TIMBCONQ	Timber producers quantity index relative to the base
PROGACRES	Thousands of acres enrolled in policy programs
TIMBINV	Total softwood and hardwood timber inventory in million cubic feet
REFOREST	Thousands of acres reforested by MIC and owner for entire United States
MICHARVEST	Thousands of acres harvested by MIC and owner for entire United States

TNEW	An enumeration of all subsidy incentive program acres in the last run; that is, in the 50 percent and subsidy incentive program run.

These tables are produced in FAFORRPT for each policy.

LANDDISP	Land actions by region and decade in thousand acres:

HARVEXST	Harvest of existing stands
HARVNEW	Harvest of reestablished stands
CONVRTFRAG	Land converted from agriculture
TRANSFER	Land lost or added to the forest base due to urban-suburban, infrastructural, and other nonfarm actions
REFOREST	Land “replanted” to any of the MIC classes (including LL MIC)
CONVRTOAG	Land shifted from forest to agriculture

SOFTEXIST	Harvest of existing softwood acres, displayed by region, land class, owner, species, and site quality. The rows show initial age class (cohort) and MIC class, and the columns show the decade of the projection in which harvested.
HARDEXIST	The same thing as SOFTEXIST for hardwood species groups
SOFTNEW and HARDNEW	Show comparable detail for reestablished stands. Each block is for region, land class, owner, species, and site quality. The rows give the MIC when regenerated and age of harvest in decades (so PLUS40 is 40 years, and so forth) and the columns show the period in the projection in which the stand was regenerated (planted). If the age of harvest is added to the decade regenerated, you can tell when the stand is next cut (for example, 1990 + 40 = 2030). Acres in thousands.
NETRADE	Shows by region, decade, and product the net offshore trade of the various regions: a positive number is a net export, a negative number a net import. Volumes in million cubic feet.
CONSBAL	Shows total U.S. consumption, production, substitution, imports, exports, and apparent consumption (as a check) of products by decade. Volumes are in million cubic feet. At times the apparent consumption check column will show a larger volume than the consumption column. The latter is the “real” amount consumed because it is possible to harvest material and not use it or downgrade (substitute) it—this may have some interesting carbon accounting consequences. [Note: The USNETSUB is the net substitution column: a positive number is material received from a higher product category and a negative number is material shifted down to a lower product category (SAWT is higher than PULP is higher than FUEL).]

LANDTOFOR	An accounting of land shifted to forestry from agriculture by region, decade, and land class
FORTOAG	Represents land shifted from forestry to agriculture by region and decade
AGTOFOR	The same totals as from LANDTOFOR but summing across the land classes
SWINTOT, and HWINTOT	Total softwood and hardwood inventories (in million cubic feet) by owner, region, and decade

Agricultural Sector Outputs

The summarized agriculture output is at the end of the FAFINAL output and gives the following information:

INDEXS — Fisher ideal price and quantity indices for a number of agriculture items giving the change in those items relative to the base model result by decade. The indices and the items in them are:

grain	CORN, SOYBEANS, WHEAT, SORGHUM, RICE, BARLEY, OATS
livestock	OTHERLIVES(MOSTLY HORSES), CULL DAIRY COWS, CULL BEEF COWS, MILK, HOGS SLAUGHTERED, FEEDER PIGS, LIVE CALVES, BEEF YEARLINGS, CALVES SLAUGHTERED, NONFED BEEF, FED BEEF, CULL SOWS, POULTRY, LAMBS SLAUGHTERED, LAMBS FOR FEEDING, CULL EWES, WOOL
othercrop	SILAGE, HAY, COTTON, SOYBEANS, SUGAR-CANE, SUGARBEET, POTATOES
feeds	FEEDGRAIN, DAIRYPROT1, HIGHPROTSW, LOWPROTSWI, LOWPROTCAT, HIGHPROTCA, GLUTENFEED
processed	SOYBEANMEA, SOYBEANOIL, FLUIDMILK, BUTTER AMCHEESE, OTCHEESE, ICECREAM, NONFATDRYM, COTTAGECHE, SKIMMILK, CREAM, HFCS, BEVERAGES, CONFECTION, BAKING, CANNING, REFSUGAR, CANEREFINI, CORNOIL, ETHANOL, COSYRUP, DEXTROSE FROZENPOT, DRIEDPOT, CHIPPOT, STARCH
meats	FEDBEEF, VEAL, NONFEDBEEF, PORK
chemicals	NITROGEN, POTASSIUM, PHOSPOROUS, LIMEIN, CHEMICALCO

	otherinput	OTHERVARIA, PUBLICGRAZ, CUSTOMOPER, SEEDCOST, CAPITAL, REPAIRCOST, VETANDMED, MARKETING, INSURANCE, MACHINERY, MANAGEMENT, LANDTAXES, GENERALOVE, NONCASHVAR, MGT, FUELANDOTH, CROPINSUR, IRRIGATION, MISCCOST, PROCCOST, TRANCOST, MISCINPUT

AGTABLE — Table of agricultural results that summarize a number of items by decade. They include:

CROPLAND	Use of cropland in thousand acres
PASTURE	Use of pastureland in thousand acres
DRYLAND	Use of dryland cropland in thousand acres
IRRIGLAND	Use of irrigated cropland in thousand acres
WATER	Use of irrigation water in thousand acre feet
LABOR	Use of labor in thousand hours
TOTALWELF	Total surplus in agriculture model in thousand dollars
CONSWELF	Total domestic agriculture consumers' surplus in agriculture model in thousand dollars
PRODWELF	Total domestic agriculture producers' surplus in agriculture model in thousand dollars
FORWELF	Total foreign surplus in agriculture model in thousand dollars
DOMESTWEL	Total domestic surplus in agriculture model in thousand dollars
GOVTCOST	Total government program cost in agriculture model in thousand dollars
NETWELF	Net agriculture surplus after subtracting government cost in thousand dollars

Adams, Darius M.; Alig, Ralph J.; Callaway, J.M.; McCarl, Bruce A.; Winnett, Steven M. 1996. The forest and agricultural sector optimization model (FASOM): model structure and policy applications. Res. Pap. PNW-RP-495. Portland, OR: U.S. Department of Agriculture, Pacific Northwest Research Station. 60 p.

The Forest and Agricultural Sector Optimization Model (FASOM) is a dynamic, nonlinear programming model of the forest and agricultural sectors in the United States. The FASOM model initially was developed to evaluate welfare and market impacts of alternative policies for sequestering carbon in trees but also has been applied to a wider range of forest and agricultural sector policy scenarios. We describe the model structure and give selected examples of policy applications. A summary of the data sources, input data file format, and the methods used to develop the input data files also are provided.

Keywords: Economics, forest sector, reforestation, afforestation, policy scenarios, models.

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